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October 29, 2002

Mr. Juan Thomas
Project Manager
United States Environmental Protection Agency
Region V (DE-9J)
77 West Jackson Street
Chicago, Illinois 60604

RE: Transmittal of Waterloo Hydrogeologic Inc. Response to Using ANOVA for Groundwater Model Calibration

Dear Mr. Thomas:

Enclosed are three copies of a Waterloo Hydrogeologic, Inc. (WHI) letter for your review. The letter dated October 22, 2002 is BASF's formal response to your verbal questions concerning using ANOVA in groundwater model calibration. Also enclosed are a copy of ASTM Standard D 5490-93 and a copy of a spreadsheet data used to generate the example graphs in the letter. The WHI letter is essentially the same as the draft letter you received during our October 17th meeting in Wyandotte.

WHI has concluded that ANOVA is not appropriate statistic for use in groundwater model calibration. WHI also concluded that R^2 is not an appropriate statistic to use.

During our telephone conversation on September 25th you requested an ANOVA and R^2 analyses of the groundwater model calibration data. Since WHI has concluded that these analyses are not appropriate, BASF will not ask WHI to generate these statistics and will not be submitting these inappropriate analyses to USEPA. Since WHI followed the ASTM standard for groundwater model calibration, BASF believes this response addresses the concerns USEPA has raised on groundwater model calibration.

If you have any questions, please contact me at (734) 324-6298.

Sincerely yours,

Bruce Roberts

Bruce Roberts
Project Manager

Enclosure

cc: Ms. Mona Sutherland – PES
Mr. Paul Martin – WHI w/o enclosure

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OCT 23 2002
QUALITY & ECOLOGY SERVICES DEPT.

Project:	Corrective Measures Study for the BASF Wyandotte North Works
Facility:	1609 Biddle Avenue Wyandotte, Michigan 48192
Respondent Project Coordinator:	Bruce Roberts, BASF Corporation
Waterloo Hydrogeologic Project Manager:	Paul J. Martin
Subject:	EPA Comment Regarding Calibration Statistics
Date:	October 22, 2002

MODEL CALIBRATION DATA

Model calibration refers to the variation of model input parameters to achieve a desired degree of correspondence between model simulations and field observations of the groundwater flow system. The most common observation of a groundwater flow system is the hydraulic head (groundwater surface elevation) at specific well locations within the model domain. This observed hydraulic head is compared to the hydraulic head values computed using the model. Observed hydraulic head values are not necessarily randomly distributed, nor are they necessarily distributed about the mean of the hydraulic head distribution on-site (the population). The observed and calculated hydraulic head values have the same distribution of data and are not independent populations. However, residual values (difference between the calculated and observed hydraulic head values) for a calibrated model are ideally considered to be normally distributed about a mean of zero.

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Typical calibration statistics for groundwater flow models are presented in ASTM Standard D 5490-93 (see attached). The distribution of residuals about a mean is typically presented as a histogram to evaluate potential bias (this bias is also quantified statistically through the mean residual value). The comparison between individual pairs of observed and calculated heads is typically presented as an X-Y scatter plot, whereby a perfect match is represented by the point falling directly on a line with a 1:1 slope and a y-intercept of zero. Second order statistics, such as the root-mean-squared error (RMS), or standard deviation, are used to evaluate the degree of scatter of the residuals about the 1:1 perfect-match line. To evaluate the potential for spatial trends in the residual values, spatial distributions of residual values are plotted.

The model calibration data presented in the Waterloo Hydrogeologic report (June, 2002) included the following calibration evaluations:

1. X-Y scatter plot of the observed and calculated head values;

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2. Statistics describing the mean residual, mean absolute residual, RMS, normalized RMS; and
3. Plot of the spatial distribution of residual values.

ANALYSIS OF VARIANCE (ANOVA) STATISTICS

Analysis of variance (ANOVA), when applied to more than one group of data, is a statistical analysis designed to compare the means of several independent groups, generally to see if the mean values are statistically different. The statistic assumes that each population is independent and the values are randomly distributed about the mean of the population.

This statistic is not appropriate for evaluation of groundwater model calibration since the observed and calibrated head values are not independent. Also, the location of the observed / calculated head values are generally not normally distributed across the whole study area. The residual values are generally randomly distributed, and thus statistical measures (mean absolute error) are used to evaluate any bias in the calibration.

LINEAR "GOODNESS OF FIT" (R^2) STATISTICS

Goodness of fit (R^2) is a statistical analysis used to evaluate how well a straight line fits the relationship between one independent and one dependent variable. This statistic assumes that the values for each population are randomly distributed about the mean of the population. When applied to a model calibration scatter plot, where the observed head is the dependent variable and the calculated head is the independent variable, the R^2 value provides a measure of how well a linear function can explain the relationship between the two variables. However, this statistic provides no insight as to how well the calculated head matches the observed head.

The R^2 value is calculated as: $R^2 = \left(\frac{COV}{S_x S_y}\right)^2$; where X = observed, Y = calculated head, and

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Covariance: $$COV = \frac{\left(\sum_1^n xy - \left(\frac{\sum_1^n x * \sum_1^n y}{n}\right)\right)}{n-1}$$

Standard Deviation of observed values: $$S_x = \sqrt{\frac{\sum_1^n \left(x - \bar{x}\right)^2}{n-1}}$$

Standard Deviation of calculated values: $$S_y = \sqrt{\frac{\sum_1^n \left(y - \bar{y}\right)^2}{n-1}}$$

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The R^2 statistic is not generally used to evaluate the quality of a model calibration because, by itself, it only provides insight into how linear the relationship is between the observed and calculated heads, and not how good the match is between pairs of observed and calculated data. However, the R^2 statistic can be applied to those models with a satisfactory RMS error, as a secondary measure of the calibration.

ROOT MEAN SQUARED (RMS) STATISTIC

Traditionally, second order statistics, such as the root-mean-squared error (RMS), or standard deviation, are used to evaluate the degree of scatter of the residuals about the 1:1 perfect-match line. In this case, the RMS or standard deviation is calculated on the residual value, not the observed or calculated populations, since the residual value is considered to be normally distributed. The RMS error is very similar to the standard deviation accept that it assumes that a complete population is sampled. It is calculated as follows:

Root-Mean-Squared Error: $RMS = \sqrt{\frac{\left(\sum_{1}^{n}(y-x)^2\right)}{n}}$

Typically the RMS error is divided by the total observed head difference across the study area to create a relative, or normalized, statistic that facilitates comparison of calibration statistics for local and regional-scale models.
Normalized RMS Error: $NRMS = RMS/(X_{max} - X_{min})$

When the model calibration exhibits a low normalized RMS and a high R^2 value, then we can have confidence that the correct trend is being simulated in the model and that the residual errors are small. The statistical fit values for the calibrated BASF North Works Model submitted to EPA (including R^2) is as follows:

Variable	*Formula*	*Value*
SP	Sxy-(Sx*Sy/n)	289.27
COV	SP/n-1	2.68
s_x^2	$(S[x^2]-(Sx)^2/n)/n-1$	2.83
s_x	$SQRT(s_x^2)$	1.68
s_y^2	$(S[y^2]-(Sy)^2/n)/n-1$	2.67
s_y	$SQRT(s_y^2)$	1.63
R	COV/s_x*s_y	0.97
R^2	$(COV/s_x*s_y)^2$	0.95
X_{Min}		572.72
X_{Max}		580.13
RMS	$SQRT(S(Y-X)^2/n)$	0.3802
NRMS	RMS/(Xmax-Xmin)	5.129%

These statistics show that for the BASF North Works model, a very good calibration was achieved (low NRMS error and a relatively high R^2 value).

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ILLUSTRATIVE EXAMPLE

To illustrate the application of these statistics, they have been applied to the sample data set provided in ASTM D5490-93 (Figure X1.2). These statistics were applied for 5 different scenarios as follows:

1. Observed and calculated heads as in the ASTM D5490-93 (Figure X1.2);
2. Calculated head values were systematically adjusted up or down 5 m to increase the spread of the data around the 1:1 perfect-match line, while maintaining the same mean value;
3. Calculated head values were systematically adjusted up or down 25 m to increase the spread of the data around the 1:1 perfect-match line, while maintaining the same mean value;
4. Calculated head values were uniformly adjusted up 25 m to increase the distance from the 1:1 perfect-match line, while maintaining a straight line; and
5. Calculated head values were multiplied by a factor to change the calculated gradient from the model.

The results of theses scenarios is presented in the following table, and illustrated in Figures 1, 2, 3, 4, and 5 respectively.

Scenario #	***1***	***2***	***3***	***4***	***5***
Description	Original Data	Calculated Heads +/- 5m	Calculated Heads +/- 25m	Calculated Heads + 25m	Wrong Gradient
RMS	1.23	5.23	25.11	25.17	13.42
Normalized RMS	2.03%	8.65%	41.56%	41. 67%	22.21%
R^2	0.99	0.79	0.11	0.99	0.98
Anova F-value	0.00203	0.00186	0.00055	59.47	0.486
Anova P-value	0.96	0.97	0.98	0.0	0.489
Anova F-critical	4.07	4.07	4.07	4.07	4.07

Note: ANOVA statistics evaluated at the 95% confidence interval.

The figures illustrate that the original data (scenario 1) provides a good match between the calculated and observed head values, while the subsequent data sets (scenarios 2-5) do not. A review of the statistical analyses in the above table shows that the RMS and Normalized RMS statistics are the best indicators of the degree of model calibration. Note that scenarios 1, 4 and 5 provide a very good R^2 value, as these plots exhibit a straight-line relationship, however that does not mean they are well calibrated. Also, note that the ANOVA statistics indicate that, for scenarios 1,2,3 and 5, the mean of the observed and calculated hydraulic heads are not significantly different (F-value less than F-critical), and therefore this statistic does not provide a good indication of the degree of calibration. In scenario 4 however, the ANOVA statistics do appropriately indicate a significant difference between the mean values of the observed and calculated heads.
From this comparison, it is clear that the RMS and Normalized RMS statistics provide the most insight into the degree of calibration of a model. The R^2 value can only be used as a secondary indicator.

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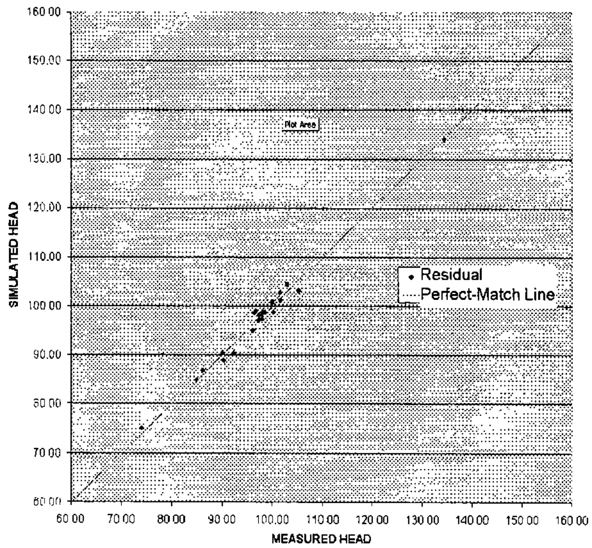

Figure 1: Original Data

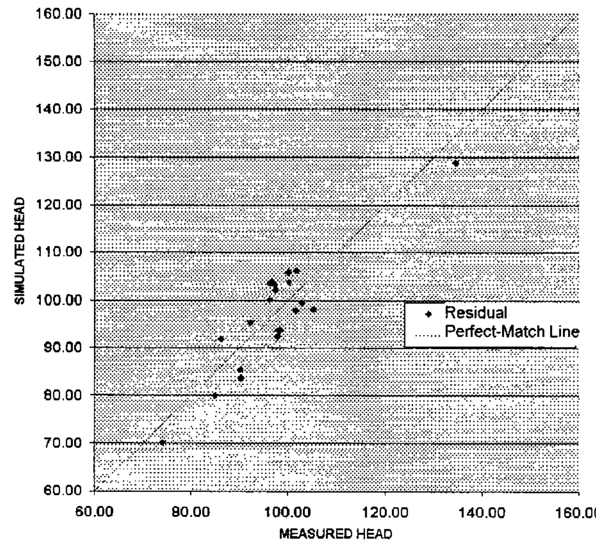

Figure 2: Calculated Heads +/- 5m

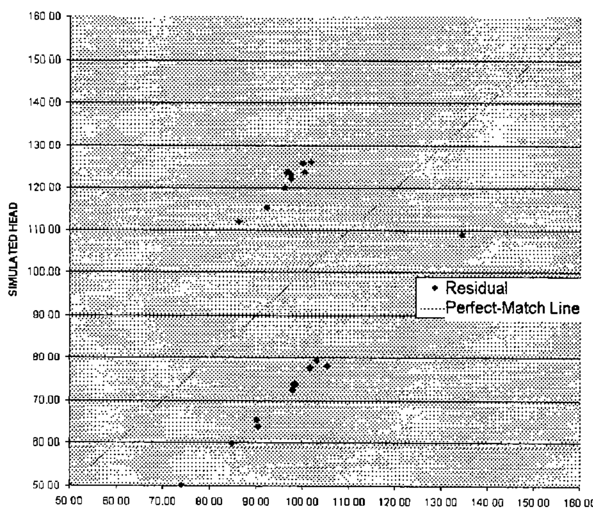

Figure 3: Calculated Heads +/- 25m

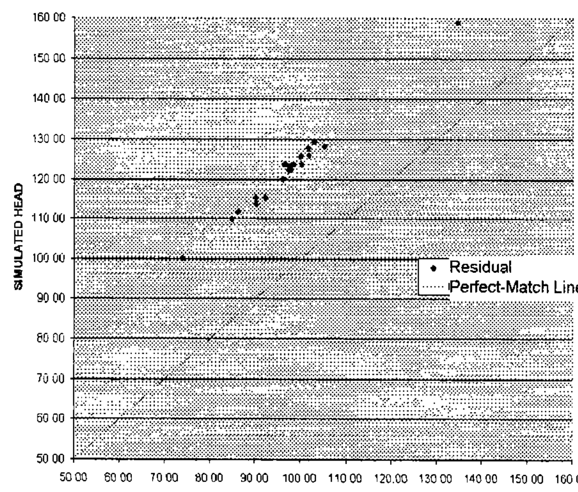

Figure 4: Calculated Heads + 25m

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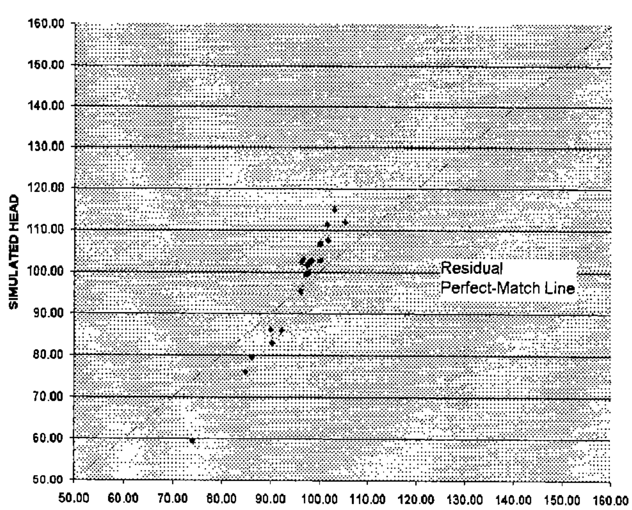

Figure 5: Wrong Gradient

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Attachment 1

ASTM D5490-93

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Standard Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information[1]

This standard is issued under the fixed designation D 5490; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers techniques that should be used to compare the results of ground-water flow model simulations to measured field data as a part of the process of calibrating a ground-water model. This comparison produces quantitative and qualitative measures of the degree of correspondence between the simulation and site-specific information related to the physical hydrogeologic system.

1.2 During the process of calibration of a ground-water flow model, each simulation is compared to site-specific information such as measured water levels or flow rates. The degree of correspondence between the simulation and the physical hydrogeologic system can then be compared to that for previous simulations to ascertain the success of previous calibration efforts and to identify potentially beneficial directions for further calibration efforts.

1.3 By necessity, all knowledge of a site is derived from observations. This guide does not address the adequacy of any set of observations for characterizing a site.

1.4 This guide does not establish criteria for successful calibration, nor does it describe techniques for establishing such criteria, nor does it describe techniques for achieving successful calibration.

1.5 This guide is written for comparing the results of numerical ground-water flow models with observed site-specific information. However, these techniques could be applied to other types of ground-water related models, such as analytical models, multiphase flow models, noncontinuum (karst or fracture flow) models, or mass transport models.

1.6 This guide is one of a series of guides on ground-water modeling codes (software) and their applications. Other standards have been prepared on environmental modeling, such as Practice E 978.

1.7 The values stated in SI units are to be regarded as the standard.

1.8 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

E 978 Practice for Evaluating Environmental Fate Models of Chemicals[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *application verification*—using the set of parameter values and boundary conditions from a calibrated model to approximate acceptably a second set of field data measured under similar hydrologic conditions.

3.1.1.1 *Discussion*—Application verification is to be distinguished from code verification which refers to software testing, comparison with analytical solutions, and comparison with other similar codes to demonstrate that the code represents its mathematical foundation.

3.1.2 *calibration*—the process of refining the model representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve a desired degree of correspondence between the model simulations and observations of the ground-water flow system.

3.1.3 *censored data*—knowledge that the value of a variable in the physical hydrogeologic system is less than or greater than a certain value, without knowing the exact value.

3.1.3.1 *Discussion*—For example, if a well is dry, then the potentiometric head at that place and time must be less than the elevation of the screened interval of the well although its specific value is unknown.

3.1.4 *conceptual model*—an interpretation or working description of the characteristics and dynamics of the physical system.

3.1.5 *ground-water flow model*—an application of a mathematical model to represent a ground-water flow system.

3.1.6 *hydrologic condition*—a set of ground-water inflows or outflows, boundary conditions, and hydraulic properties that cause potentiometric heads to adopt a distinct pattern.

3.1.7 *residual*—the difference between the computed and

[1] This guide is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Ground Water and Vadose Zone Investigations.

Current edition approved Nov. 15, 1993. Published January 1994.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] *Annual Book of ASTM Standards*, Vol 11.04.

observed values of a variable at a specific time and location.

3.1.8 *simulation*—in ground-water flow modeling, one complete execution of a ground-water modeling computer program, including input and output.

3.1.8.1 *Discussion*—For the purposes of this guide, a simulation refers to an individual modeling run. However, simulation is sometimes also used broadly to refer to the process of modeling in general.

3.2 For definitions of other terms used in this guide, see Terminology D 653.

4. Summary of Guide

4.1 Quantitative and qualitative comparisons are both essential. Both should be used to evaluate the degree of correspondence between a ground-water flow model simulation and site-specific information.

4.2 Quantitative techniques for comparing a simulation with site-specific information include:

4.2.1 Calculation of residuals between simulated and measured potentiometric heads and calculation of statistics regarding the residuals. Censored data resulting from detection of dry or flowing observation wells, reflecting information that the head is less than or greater than a certain value without knowing the exact value, should also be used.

4.2.2 Detection of correlations among residuals. Spatial and temporal correlations among residuals should be investigated. Correlations between residuals and potentiometric heads can be detected using a scattergram.

4.2.3 Calculation of flow-related residuals. Model results should be compared to flow data, such as water budgets, surface water flow rates, flowing well discharges, vertical gradients, and contaminant plume trajectories.

4.3 Qualitative considerations for comparing a simulation with site-specific information include:

4.3.1 Comparison of general flow features. Simulations should reproduce qualitative features in the pattern of ground-water contours, including ground-water flow directions, mounds or depressions (closed contours), or indications of surface water discharge or recharge (cusps in the contours).

4.3.2 Assessment of the number of distinct hydrologic conditions to which the model has been successfully calibrated. It is usually better to calibrate to multiple scenarios, if the scenarios are truly distinct.

4.3.3 Assessment of the reasonableness or justifiability of the input aquifer hydrologic properties given the aquifer materials which are being modeled. Modeled aquifer hydrologic properties should fall within realistic ranges for the physical hydrogeologic system, as defined during conceptual model development.

5. Significance and Use

5.1 During the process of calibration of a ground-water flow model, each simulation is compared to site-specific information to ascertain the success of previous calibration efforts and to identify potentially beneficial directions for further calibration efforts. Procedures described herein provide guidance for making comparisons between ground-water flow model simulations and measured field data.

5.2 This guide is not meant to be an inflexible description of techniques comparing simulations with measured data; other techniques may be applied as appropriate and, after due consideration, some of the techniques herein may be omitted, altered, or enhanced.

6. Quantitative Techniques

6.1 Quantitative techniques for comparing simulations to site-specific information include calculating potentiometric head residuals, assessing correlation among head residuals, and calculating flow residuals.

6.1.1 *Potentiometric Head Residuals*—Calculate the residuals (differences) between the computed heads and the measured heads:

$$r_i = h_i - H_i \tag{1}$$

where:

r_i = the residual,
H_i = the measured head at point i,
h_i = the computed head at the approximate location where H_i was measured.

If the residual is positive, then the computed head was too high; if negative, the computed head was too low. Residuals cannot be calculated from censored data.

NOTE 1—For drawdown models, residuals can be calculated from computed and measured drawdowns rather than heads.

NOTE 2—Comparisons should be made between point potentiometric heads rather than ground-water contours, because contours are the result of interpretation of data points and are not considered basic data in and of themselves.[4] Instead, the ground-water contours are considered to reflect features of the conceptual model of the site. The ground-water flow model should be true to the essential features of the conceptual model and not to their representation.

NOTE 3—It is desirable to set up the model so that it calculates heads at the times and locations where they were measured, but this is not always possible or practical. In cases where the location of a monitoring well does not correspond exactly to one of the nodes where heads are computed in the simulation, the residual may be adjusted (for example, computed heads may be interpolated, extrapolated, scaled, or otherwise transformed) for use in calculating statistics. Adjustments may also be necessary when the times of measurements do not correspond exactly with the times when heads are calculated in transient simulations; when many observed heads are clustered near a single node; where the hydraulic gradient changes significantly from node to node; or when observed head data is affected by tidal fluctuations or proximity to a specified head boundary.

6.1.2 *Residual Statistics*—Calculate the maximum and minimum residuals, a residual mean, and a second-order statistic, as described in the following sections.

6.1.2.1 *Maximum and Minimum Residuals*—The maximum residual is the residual that is closest to positive infinity. The minimum residual is the residual closest to negative infinity. Of two simulations, the one with the maximum and minimum residuals closest to zero has a better degree of correspondence, with regard to this criterion.

NOTE 4—When multiple hydrologic conditions are being modeled as separate steady-state simulations, the maximum and minimum residual can be calculated for the residuals in each, or for all residuals in all scenarios, as appropriate. This note also applies to the residual mean (see 6.1.2.2) and second-order statistics of the residuals (see 6.1.2.4).

[4] Cooley, R. L., and Naff, R. L., "Regression Modeling of Ground-Water Flow," *USGS Techniques of Water Resources Investigations*, Book 3, Chapter B4, 1990.

6.1.2.2 *Residual Mean*—Calculate the residual mean as the arithmetic mean of the residuals computed from a given simulation:

$$R = \frac{\sum_{i=1}^{n} r_i}{n} \qquad (2)$$

where:
R = the residual mean and
n = the number of residuals.

Of two simulations, the one with the residual mean closest to zero has a better degree of correspondence, with regard to this criterion (assuming there is no correlation among residuals).

6.1.2.3 If desired, the individual residuals can be weighted to account for differing degrees of confidence in the measured heads. In this case, the residual mean becomes the weighted residual mean:

$$R = \frac{\sum_{i=1}^{n} w_i r_i}{n \sum_{i=1}^{n} w_i} \qquad (3)$$

where w_i is the weighting factor for the residual at point i. The weighting factors can be based on the modeler's judgment or statistical measures of the variability in the water level measurements. A higher weighting factor should be used for a measurement with a high degree of confidence than for one with a low degree of confidence.

NOTE 5—It is possible that large positive and negative residuals could cancel, resulting in a small residual mean. For this reason, the residual mean should never be considered alone, but rather always in conjunction with the other quantitative and qualitative comparisons.

6.1.2.4 *Second-Order Statistics*—Second-order statistics give measures of the amount of spread of the residuals about the residual mean. The most common second-order statistic is the standard deviation of residuals:

$$s = \left\{ \frac{\sum_{i=1}^{n} (r_i - R)^2}{(n-1)} \right\}^{\frac{1}{2}} \qquad (4)$$

where s is the standard deviation of residuals. Smaller values of the standard deviation indicate better degrees of correspondence than larger values.

6.1.2.5 If weighting is used, calculate the weighted standard deviation:

$$s = \left\{ \frac{\sum_{i=1}^{n} w_i (r_i - R)^2}{(n-1) \sum_{i=1}^{n} w_i} \right\}^{\frac{1}{2}} \qquad (5)$$

NOTE 6—Other norms of the residuals are less common but may be revealing in certain cases.[5,6] For example, the mean of the absolute values of the residuals can give information similar to that of the standard deviation of residuals.

NOTE 7—In calculating the standard deviation of residuals, advanced statistical techniques incorporating information from censored data could be used. However, the effort would usually not be justified because the standard deviation of residuals is only one of many indicators involved in comparing a simulation with measured data, and such a refinement in one indicator is unlikely to alter the overall assessment of the degree of correspondence.

6.1.3 *Correlation Among Residuals*—Spatial or temporal correlation among residuals can indicate systematic trends or bias in the model. Correlations among residuals can be identified through listings, scattergrams, and spatial or temporal plots. Of two simulations, the one with less correlation among residuals has a better degree of correspondence, with regard to this criterion.

6.1.3.1 *Listings*—List residuals by well or piezometer, including the measured and computed values to detect spatial or temporal trends. Figures X1.1 and X1.2 present example listings of residuals.

6.1.3.2 *Scattergram*—Use a scattergram of computed versus measured heads to detect trends in deviations. The scattergram is produced with measured heads on the abscissa (horizontal axis) and computed heads on the ordinate (vertical axis). One point is plotted on this graph for each pair. If the points line up along a line with zero intercept and 45° angle, then there has been a perfect match. Usually, there will be some scatter about this line, hence the name of the plot. A simulation with a small degree of scatter about this line has a better correspondence with the physical hydrogeologic system than a simulation with a large degree of scatter. In addition, plotted points in any area of the scattergram should not all be grouped above or below the line. Figures X1.3 and X1.4 show sample scattergrams.

6.1.3.3 *Spatial Correlation*—Plot residuals in plan or section to identify spatial trends in residuals. In this plot, the residuals, including their sign, are plotted on a site map or cross section. If possible or appropriate, the residuals can also be contoured. Apparent trends or spatial correlations in the residuals may indicate a need to refine aquifer parameters or boundary conditions, or even to reevaluate the conceptual model (for example, add spatial dimensions or physical processes). For example, if all of the residuals in the vicinity of a no-flow boundary are positive, then the recharge may need to be reduced or the hydraulic conductivity increased. Figure X1.5 presents an example of a contour plot of residuals in plan view. Figure X1.6 presents an example of a plot of residuals in cross section.

6.1.3.4 *Temporal Correlation*—For transient simulations, plot residuals at a single point versus time to identify temporal trends. Temporal correlations in residuals can indicate the need to refine input aquifer storage properties or initial conditions. Figure X1.7 presents a typical plot of residuals versus time.

6.1.4 *Flow-Related Residuals*—Often, information relating to ground-water velocities is available for a site. Examples include water budgets, surface water flow rates, flowing well discharges, vertical gradients, and contaminant plume trajectories (ground-water flow paths). All such quantities are dependent on the hydraulic gradient (the spatial derivative of the potentiometric head). Therefore, they relate to the overall

[5] Ghassemi, F., Jakeman, A. J., and Thomas, G. A., "Ground-Water Modeling for Salinity Management: An Australian Case Study," *Ground Water*, Vol 27, No. 3, 1989, pp. 384–392.

[6] Konikow, L. F., *Calibration of Ground-Water Models, Proceedings of the Specialty Conference on Verification of Mathematical and Physical Models in Hydraulic Engineering*, ASCE, College Park, MD, Aug. 9–11, 1978, pp. 87–93.

structure of the pattern of potentiometric heads and provide information not available from point head measurements. For each such datum available, calculate the residual between its computed and measured values. If possible and appropriate, calculate statistics on these residuals and assess their correlations, in the manner described in 5.1 and 5.2 for potentiometric head residuals.

6.1.4.1 *Water Budgets and Mass Balance*—For elements of the water budget for a site which are calculated (as opposed to specified in the model input) (for example, base flow to a stream), compare the computed and the measured (or estimated) values. In addition, check the computed mass balance for the simulation by comparing the sum of all inflows to the sum of all outflows and changes in storage. Differences of more than a few percent in the mass balance indicate possible numerical problems and may invalidate simulation results.

6.1.4.2 *Vertical Gradients*—In some models, it may be more important to accurately represent the difference in heads above and below a confining layer, rather than to reproduce the heads themselves. In such a case, it may be acceptable to tolerate a correlation between the head residuals above and below the layer if the residual in the vertical gradient is minimized.

6.1.4.3 *Ground-Water Flow Paths*—In some models, it may be more important to reproduce the pattern of streamlines in the ground-water flow system rather than to reproduce the heads themselves (for example, when a flow model is to be used for input of velocities into a contaminant transport model). In this case, as with the case of vertical gradients in 6.1.4.2 it may be acceptable to tolerate some correlation in head residuals if the ground-water velocity (magnitude and direction) residuals are minimized.

7. Qualitative Considerations

7.1 *General Flow Features*—One criterion for evaluating the degree of correspondence between a ground-water flow model simulation and the physical hydrogeologic system is whether or not essential qualitative features of the potentiometric surface are reflected in the model. The overall pattern of flow directions and temporal variations in the model should correspond with those at the site. For example:

7.1.1 If there is a mound or depression in the potentiometric surface at the site, then the modeled contours should also indicate a mound or depression in approximately the same area.

7.1.2 If measured heads indicate or imply cusps in the ground-water contours at a stream, then these features should also appear in contours of modeled heads.

7.2 *Hydrologic Conditions*—Identify the different hydrologic conditions that are represented by the available data sets. Choose one data set from each hydrologic condition to use for calibration. Use the remaining sets for verification.

7.2.1 *Uniqueness (Distinct Hydrologic Conditions)*—The number of distinct hydrologic conditions that a given set of input aquifer hydrologic properties is capable of representing is an important qualitative measure of the performance of a model. It is usually better to calibrate to multiple conditions, if the conditions are truly distinct. Different hydrologic conditions include, but are not limited to, high and low recharge; conditions before and after pumping or installation of a cutoff wall or cap; and high and low tides, flood stages for adjoining surface waters, or installation of drains. By matching different hydrologic conditions, the uniqueness problem is addressed, because one set of heads can be matched with the proper ratio of ground-water flow rates to hydraulic conductivities; whereas, when the flow rates are changed, representing a different condition, the range of acceptable hydraulic conductivities becomes much more limited.

7.2.2 *Verification (Similar Hydrologic Conditions)*—When piezometric head data are available for two times of similar hydrologic conditions, only one of those conditions should be included in the calibration data sets because they are not distinct. However, the other data set can be used for model verification. In the verification process, the modeled piezometric heads representing the hydrologic condition in question are compared, not to the calibration data set, but to the verification data set. The resulting degree of correspondence can be taken as an indicator or heuristic measure of the ability of the model to represent new hydrologic conditions within the range of those to which the model was calibrated.

NOTE 8—When only one data set is available, it is inadvisable to artificially split it into separate "calibration" and "verification" data sets. It is usually more important to calibrate to piezometric head data spanning as much of the modeled domain as possible.

NOTE 9—Some researchers maintain that the word "verification" implies a higher degree of confidence than is warranted.[7] Used here, the verification process only provides a method for estimating confidence intervals on model predictions.

7.3 *Input Aquifer Hydraulic Properties*—A good correspondence between a ground-water flow model simulation and site-specific information, in terms of quantitative measures, may sometimes be achieved using unrealistic aquifer hydraulic properties. This is one reason why emphasis is placed on the ability to reproduce multiple distinct hydrologic stress scenarios. Thus, a qualitative check on the degree of correspondence between a simulation and the physical hydrogeologic system should include an assessment of the likely ranges of hydraulic properties for the physical hydrogeologic system at the scale of the model or model cells and whether the properties used in the model lie within those ranges.

8. Report

8.1 When a report for a ground-water flow model application is produced, it should include a description of the above comparison tests which were performed, the rationale for selecting or omitting comparison tests, and the results of those comparison tests.

9. Keywords

9.1 calibration; computer; ground water; modeling

[7] Konikow, L. F., and Bredehoeft, J. D., "Ground-Water Models Cannot Be Validated," *Adv. Wat. Res.* Vol 15, 1992, pp. 75–83.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLES

X1.1 Fig. X1.1 and Fig. X1.2 present sample listings of residuals, as described in 6.1.3.1. These listings tabulate the residuals for simulations of two hydrologic conditions with the same model. Note that some of the wells do not have measurements for both simulations. Simulated heads for these wells are still reported as an aid to detecting temporal trends in the heads for different aquifer stresses. Some censored water level data were available for this site. For these data, the table merely indicates whether or not the simulation is consistent with the censored data.

X1.2 Fig. X1.3 and Fig. X1.4 show sample scattergrams, as described in 6.1.3.2. The scattergram on Fig. X1.3 indicates a good match between modeled and measured potentiometric heads because there is little or no pattern between positive and negative residuals and because the magnitude of the residuals is small compared to the total change in potentiometric head across the site. The residuals shown on the scattergram on Fig. X1.4 have the same maximum, minimum, mean, and standard deviation as those shown on Fig. X1.3, but show a pattern of positiveresiduals upgradient and negative residuals downgradient. However, even though the statistical comparisons would indicate a good degree of correspondence, this model may overestimate seepage velocities because the simulated hydraulic gradient is higher than the measured hydraulic gradient. Therefore this model may need to be improved if the heads are to be input into a mass transport model.

X1.3 Fig. X1.5 and Fig. X1.6 show sample plots of

Example Site
Stress scenario #1
Simulation #24-1

Residuals:

Number of residuals	: 18
Maximum residual	(m) : 2.62 at MW-31
Minimum residual	(m) : -2.51 at MW-5
Residual mean	(m) : 0.15
Standard deviation of residuals	(m) : 1.49

Censored Data:

Number of inequalities met	: 1
Number of inequalities not met	: 1

WELL	MEASURED HEAD (M)	SIMULATED HEAD (M)	RESIDUAL (M)
MW-1	100.79	101.57	0.78
MW-2	104.52	103.14	-1.38
MW-3	103.07	101.26	-1.81
MW-4	<101.10	100.97	YES
MW-5	106.82	104.31	-2.51
MW-6	99.94	100.39	0.45
MW-7	101.43	102.84	1.41
MW-8	89.26	89.43	0.17
MW-9	89.34	87.53	-1.81
MW-10	<97.97	98.02	NO
MW-11		96.94	
MW-12		88.60	
MW-13		91.85	
MW-14		77.57	
MW-15		103.04	
MW-16		103.12	
MW-17	95.44	97.84	2.40
MW-18		104.80	
MW-19		95.32	
MW-20		103.14	
MW-21		94.31	
MW-22	101.02	99.54	-1.48
MW-23	70.79	71.69	0.90
MW-24		99.09	
MW-25		100.80	
MW-26	98.26	98.23	-0.03
MW-27	87.44	89.03	1.59
MW-28		98.79	
MW-29	83.30	83.14	-0.16
MW-30	82.99	85.03	2.04
MW-31	95.51	98.13	2.62
MW-32	97.63	97.80	0.17
MW-33	134.02	133.46	-0.56

FIG. X1.1 Example Listings of Residuals

Example Site
Stress scenario #2
Simulation #24-2

Residuals:

Number of residuals	: 22
Maximum residual	(m) : 2.30 at MW-24
Minimum residual	(m) : -2.15 at MW-20
Residual mean	(m) : 0.15
Standard deviation of residuals	(m) : 1.22

Censored Data:

Number of inequalities met	: 2
Number of inequalities not met	: 0

WELL	MEASURED HEAD (m)	SIMULATED HEAD (m)	RESIDUAL (m)
MW-1	101.72	101.11	-0.61
MW-2	98.43	98.77	0.34
MW-3	100.04	100.80	0.76
MW-4	<101.10	100.57	YES
MW-5	102.95	104.45	1.50
MW-6	100.00	100.66	0.66
MW-7	101.56	102.80	1.24
MW-8	92.24	90.42	-1.82
MW-9	90.34	88.77	-1.57
MW-10	<97.97	96.88	YES
MW-11		97.69	
MW-12		90.01	
MW-13		93.43	
MW-14		80.27	
MW-15		103.58	
MW-16		103.32	
MW-17	96.33	98.62	2.29
MW-18		105.73	
MW-19		96.65	
MW-20	105.25	103.10	-2.15
MW-21	96.10	95.11	-0.99
MW-22		99.63	
MW-23	74.01	75.21	1.20
MW-24	96.66	98.96	2.30
MW-25	98.04	98.71	0.67
MW-26	97.39	98.21	0.82
MW-27	90.11	90.48	0.37
MW-28	100.23	98.76	-1.47
MW-29	84.92	84.98	0.06
MW-30	86.15	86.88	0.73
MW-31	97.87	97.38	-0.49
MW-32	97.31	97.17	-0.14
MW-33	134.43	133.96	-0.47

FIG. X1.2 Example Listings of Residuals

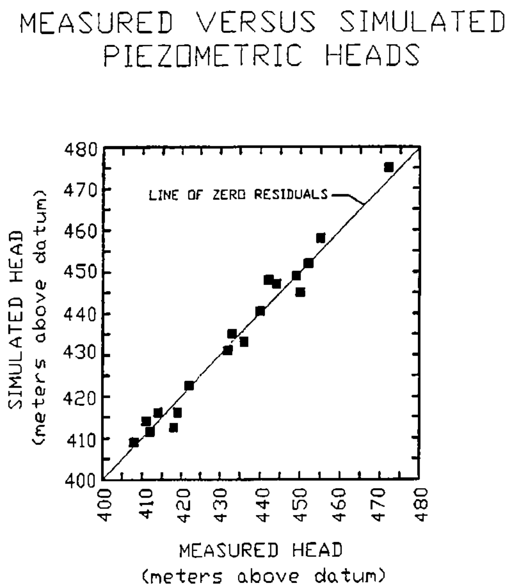

FIG. X1.3 Sample Scattergram

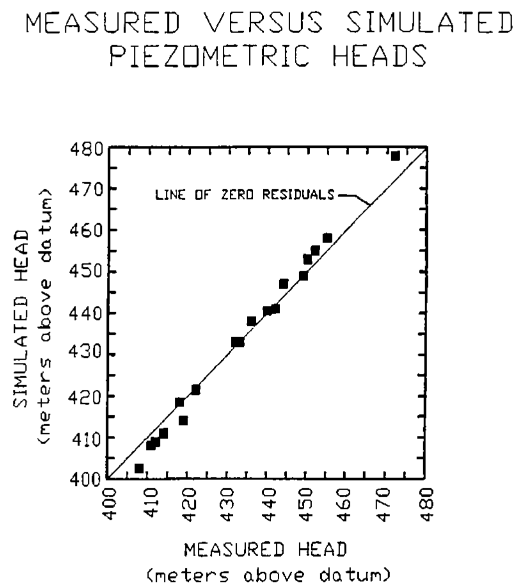

FIG. X1.4 Sample Scattergram

residuals in plan and cross-section, as described in 6.1.3.3. In Fig. X1.5, there are sufficient data to contour the residuals. The contours indicate potentially significant correlations between residuals in the northwest and southwest corners of the model. Along the river, the residuals appear to be uncorrelated. In Fig. X1.6, residuals were not contoured due to their sparseness and apparent lack of correlation.

X1.4 Fig. X1.7 shows a sample plot of measured and simulated potentiometric heads and their residuals for one well in a transient simulation, as described in 6.1.3.4. The upper graph shows the measured potentiometric head at the well as measured using a pressure transducer connected to a data logger. In addition, simulated potentiometric heads for the same time period are also shown. The lower graph shows the residuals. This example shows how residuals can appear uncorrelated in a model that does not represent essential characteristics of the physical hydrogeologic system, in this case by not reproducing the correct number of maxima and minima.

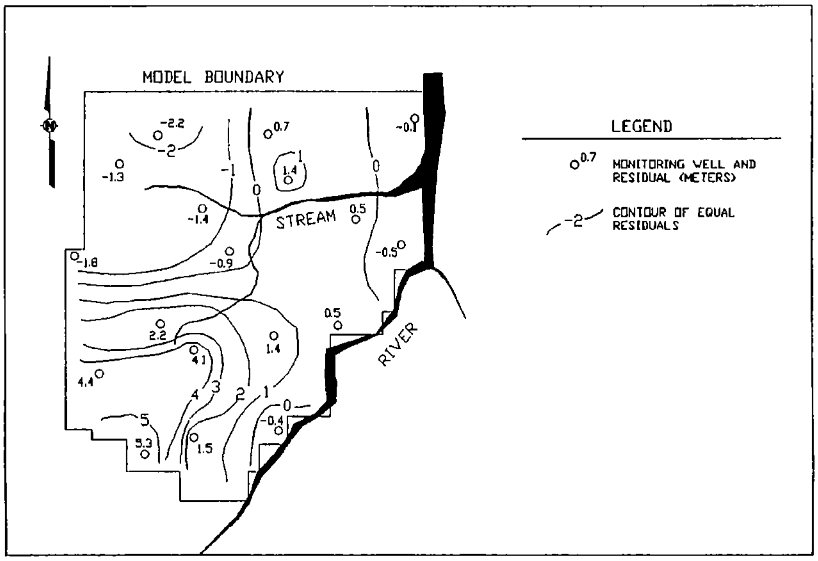

FIG. X1.5 Sample Contours of Residuals Plan View

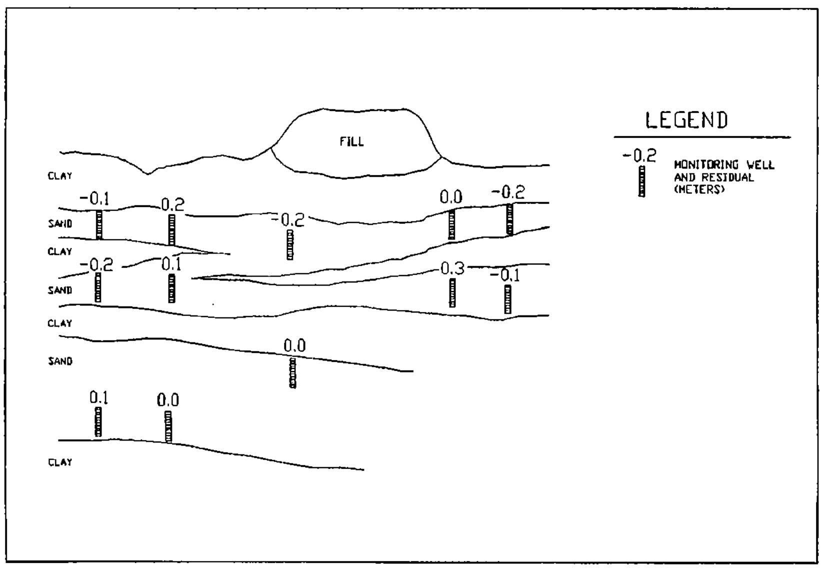

FIG. X1.6 Sample Plot of Residuals Section View

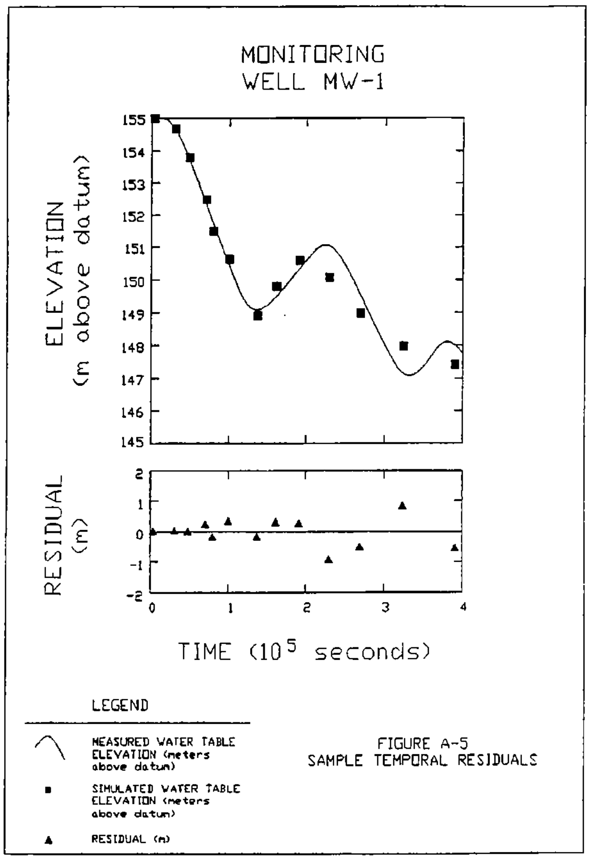

FIG. X1.7 Sample Temporal Residuals

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Attachment 2

Results from Microsoft EXCEL Spreadsheets for the 5 Scenarios.

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Information from ASTM D5490 Fig. X1.2

WELL	MEASURED HEAD	SIMULATED HEAD	RESIDUAL	RESIDUAL SQ
MW-1	101.72	101.11	-0.61	0.3721
MW-2	98.43	98.77	0.34	0.1156
MW-3	100.04	100.80	0.76	0.5776
MW-5	102.95	104.45	1.50	2.25
MW-6	100.00	100.66	0.66	0.4356
MW-7	101.56	102.80	1.24	1.5376
MW-8	92.24	90.42	-1.82	3.3124
MW-9	90.34	88.77	-1.57	2.4649
MW-17	96.33	98.62	2.29	5.2441
MW-20	105.25	103.10	-2.15	4.6225
MW-21	96.10	95.11	-0.99	0.9801
MW-23	74.01	75.21	1.20	1.44
MW-24	96.66	98.96	2.30	5.29
MW-25	98.04	98.71	0.67	0.4489
MW-26	97.39	98.21	0.82	0.6724
MW-27	90.11	90.48	0.37	0.1369
MW-28	100.23	98.76	-1.47	2.1609
MW-29	84.92	84.98	0.06	0.0036
MW-30	86.15	86.88	0.73	0.5329
MW-31	97.87	97.38	-0.49	0.2401
MW-32	97.31	97.17	-0.14	0.0196
MW-33	134.43	133.96	-0.47	0.2209
	60.00	60.00		
	160.00	160.00		
MEAN	97.37	97.51		
VARIANCE	118.35	115.59		
RMS				1.226204417
NRMS				2.03%

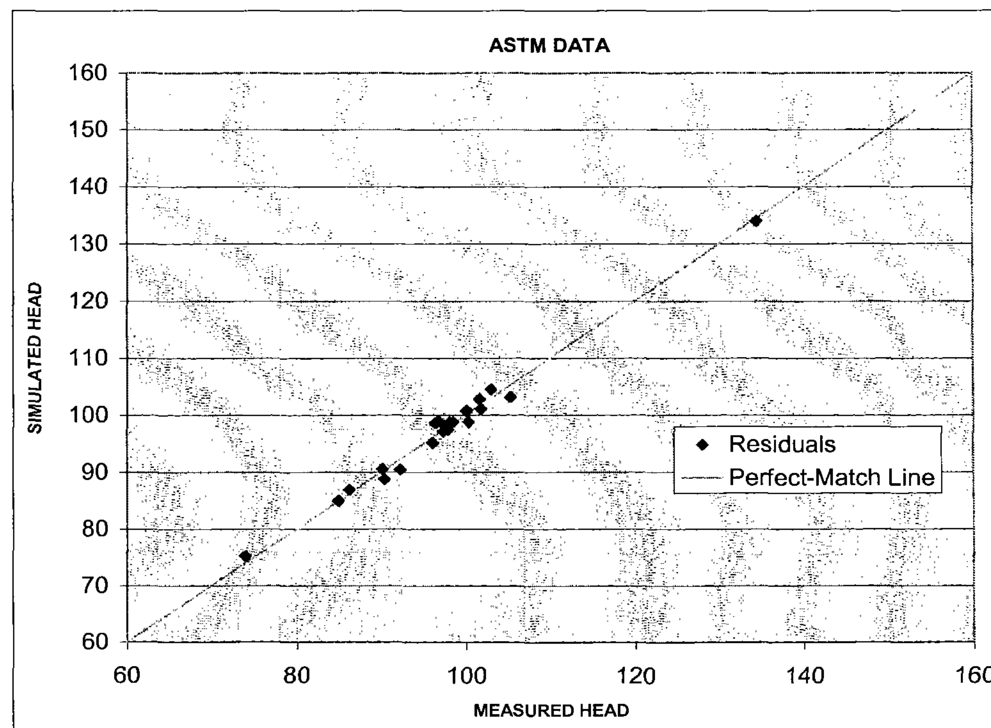
Well Name	X(Obs)	X^2	Y(Calc)	Y^2	XY	$(Y-X)^2$
MW-1	101.72	10346.96	101.11	10223.23	10284.91	0.37
MW-2	98.43	9688.46	98.77	9755.51	9721.93	0.12
MW-3	100.04	10008.00	100.80	10160.64	10084.03	0.58
MW-5	102.95	10598.70	104.45	10909.80	10753.13	2.25
MW-6	100.00	10000.00	100.66	10132.44	10066.00	0.44
MW-7	101.56	10314.43	102.80	10567.84	10440.37	1.54
MW-8	92.24	8508.22	90.42	8175.78	8340.34	3.31
MW-9	90.34	8161.32	88.77	7880.11	8019.48	2.46
MW-17	96.33	9279.47	98.62	9725.90	9500.06	5.24
MW-20	105.25	11077.56	103.10	10629.61	10851.28	4.62
MW-21	96.10	9235.21	95.11	9045.91	9140.07	0.98
MW-23	74.01	5477.48	75.21	5656.54	5566.29	1.44
MW-24	96.66	9343.16	98.96	9793.08	9565.47	5.29
MW-25	98.04	9611.84	98.71	9743.66	9677.53	0.45
MW-26	97.39	9484.81	98.21	9645.20	9564.67	0.67
MW-27	90.11	8119.81	90.48	8186.63	8153.15	0.14
MW-28	100.23	10046.05	98.76	9753.54	9898.71	2.16
MW-29	84.92	7211.41	84.98	7221.60	7216.50	0.00
MW-30	86.15	7421.82	86.88	7548.13	7484.71	0.53
MW-31	97.87	9578.54	97.38	9482.86	9530.58	0.24
MW-32	97.31	9469.24	97.17	9442.01	9455.61	0.02
MW-33	134.43	18071.42	133.96	17945.28	18008.24	0.22

Statistics

Sxy=		211323.08
Sx=		2142.08
Sx^2		211053.92
Sy=		2145.31
Sy^2		211625.33
$S(Y-X)^2$		33.08
n=		22
XMin		74.01
XMax		134.43
SP =	Sxy-(Sx*Sy/n)	2440.10
COV=	SP/n-1	116.20
s_x^2=	^{2}]-$(Sx)^2$/n)/n-1	118.35
s_x=	SQRT(s_x^2)	10.88
s_y^2=	^{2}]-$(Sy)^2$/n)/n-1	115.59
s_y=	SQRT(s_y^2)	10.75
r=	COV/s_x*s_y	0.99
r^2=		0.99

Visual MODFLOW

RMS=	SQRT(S(Y-X)	1.2262
NRMS=	RMS/(Xmax-X	2.029%



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	22	2142.08	97.367273	118.3537732
Column 2	22	2145.31	97.514091	115.5893396

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.237111364	1	0.2371114	0.002027086	0.964302	4.07266
Within Groups	4912.805368	42	116.97156			
Total	4913.04248	43				

Information from ASTM D5490 Fig. X1.2 plus minus 5

WELL	MEASURED HEAD	SIMULATED HEAD	RESIDUAL	RESIDUAL SQ
MW-1	101.72	106.11	4.39	19.2721
MW-2	98.43	93.77	-4.66	21.7156
MW-3	100.04	105.80	5.76	33.1776
MW-5	102.95	99.45	-3.50	12.25
MW-6	100.00	105.66	5.66	32.0356
MW-7	101.56	97.80	-3.76	14.1376
MW-8	92.24	95.42	3.18	10.1124
MW-9	90.34	83.77	-6.57	43.1649
MW-17	96.33	103.62	7.29	53.1441
MW-20	105.25	98.10	-7.15	51.1225
MW-21	96.10	100.11	4.01	16.0801
MW-23	74.01	70.21	-3.80	14.44
MW-24	96.66	103.96	7.30	53.29
MW-25	98.04	93.71	-4.33	18.7489
MW-26	97.39	103.21	5.82	33.8724
MW-27	90.11	85.48	-4.63	21.4369
MW-28	100.23	103.76	3.53	12.4609
MW-29	84.92	79.98	-4.94	24.4036
MW-30	86.15	91.88	5.73	32.8329
MW-31	97.87	92.38	-5.49	30.1401
MW-32	97.31	102.17	4.86	23.6196
MW-33	134.43	128.96	-5.47	29.9209
	60.00	60.00		
	160.00	160.00		
MEAN	97.37	97.51		
VARIANCE	118.35	136.11		
RMS				5.228326257
NRMS				8.65%

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	22	2142.08	97.367273	118.3537732
Column 2	22	2145.31	97.514091	136.1083872

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.237111364	1	0.2371114	0.001863628	0.965771	4.07266
Within Groups	5343.705368	42	127.23108			
Total	5343.94248	43				

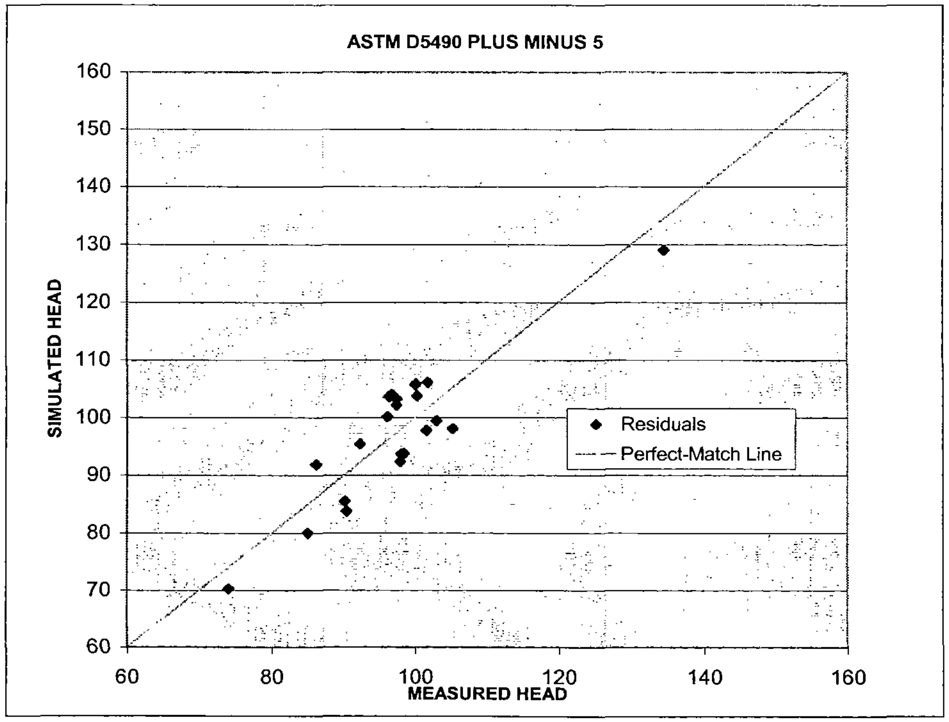
Well Name	X(Obs)	X^2	Y(Calc)	Y^2	XY	$(Y-X)^2$
MW-1	101.72	10346.96	106.11	11259.33	10793.51	19.27
MW-2	98.43	9688.46	93.77	8792.81	9229.78	21.72
MW-3	100.04	10008.00	105.80	11193.64	10584.23	33.18
MW-5	102.95	10598.70	99.45	9890.30	10238.38	12.25
MW-6	100.00	10000.00	105.66	11164.04	10566.00	32.04
MW-7	101.56	10314.43	97.80	9564.84	9932.57	14.14
MW-8	92.24	8508.22	95.42	9104.98	8801.54	10.11
MW-9	90.34	8161.32	83.77	7017.41	7567.78	43.16
MW-17	96.33	9279.47	103.62	10737.10	9981.71	53.14
MW-20	105.25	11077.56	98.10	9623.61	10325.03	51.12
MW-21	96.10	9235.21	100.11	10022.01	9620.57	16.08
MW-23	74.01	5477.48	70.21	4929.44	5196.24	14.44
MW-24	96.66	9343.16	103.96	10807.68	10048.77	53.29
MW-25	98.04	9611.84	93.71	8781.56	9187.33	18.75
MW-26	97.39	9484.81	103.21	10652.30	10051.62	33.87
MW-27	90.11	8119.81	85.48	7306.83	7702.60	21.44
MW-28	100.23	10046.05	103.76	10766.14	10399.86	12.46
MW-29	84.92	7211.41	79.98	6396.80	6791.90	24.40
MW-30	86.15	7421.82	91.88	8441.93	7915.46	32.83
MW-31	97.87	9578.54	92.38	8534.06	9041.23	30.14
MW-32	97.31	9469.24	102.17	10438.71	9942.16	23.62
MW-33	134.43	18071.42	128.96	16630.68	17336.09	29.92

Statistics

Sxy=		211254.38
Sx=		2142.08
Sx^2		211053.92
Sy=		2145.31
Sy^2		212056.23
$S(Y-X)^2$		601.38
n=		22
XMin		74.01
XMax		134.43
SP =	Sxy-(Sx*Sy/n)	2371.40
COV=	SP/n-1	112.92
s_x^2=	²]-(Sx)²/n)/n-1	118.35
s_x=	SQRT(s_x^2)	10.88
s_y^2=	²]-(Sy)²/n)/n-1	136.11
s_y=	SQRT(s_y^2)	11.67
r=	COV/s_x*s_y	0.89
r^2=		0.79

Visual MODFLOW

RMS=	SQRT(S(Y-X)	5.2283
NRMS=	RMS/(Xmax-)	8.653%



Information from AST[illegible]490 Fig. X1.2 plus minus 25

WELL	MEASURED HEAD	SIMULATED HEAD	RESIDUAL	RESIDUAL SQ
MW-1	101.72	126.11	24.39	594.8721
MW-2	98.43	73.77	-24.66	608.1156
MW-3	100.04	125.80	25.76	663.5776
MW-5	102.95	79.45	-23.50	552.25
MW-6	100.00	125.66	25.66	658.4356
MW-7	101.56	77.80	-23.76	564.5376
MW-8	92.24	115.42	23.18	537.3124
MW-9	90.34	63.77	-26.57	705.9649
MW-17	96.33	123.62	27.29	744.7441
MW-20	105.25	78.10	-27.15	737.1225
MW-21	96.10	120.11	24.01	576.4801
MW-23	74.01	50.21	-23.80	566.44
MW-24	96.66	123.96	27.30	745.29
MW-25	98.04	73.71	-24.33	591.9489
MW-26	97.39	123.21	25.82	666.6724
MW-27	90.11	65.48	-24.63	606.6369
MW-28	100.23	123.76	23.53	553.6609
MW-29	84.92	59.98	-24.94	622.0036
MW-30	86.15	111.88	25.73	662.0329
MW-31	97.87	72.38	-25.49	649.7401
MW-32	97.31	122.17	24.86	618.0196
MW-33	134.43	108.96	-25.47	648.7209
	50.00	50.00		
	160.00	160.00		
MEAN	97.37	97.51		
VARIANCE	118.35	741.99		
RMS				25.11299799
NRMS				41.56%

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	22	2142.08	97.367273	118.3537732
Column 2	22	2145.31	97.514091	741.9941015

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.237111364	1	0.2371114	0.000551199	0.98138	4.07266
Within Groups	18067.30537	42	430.17394			
Total	18067.54248	43				

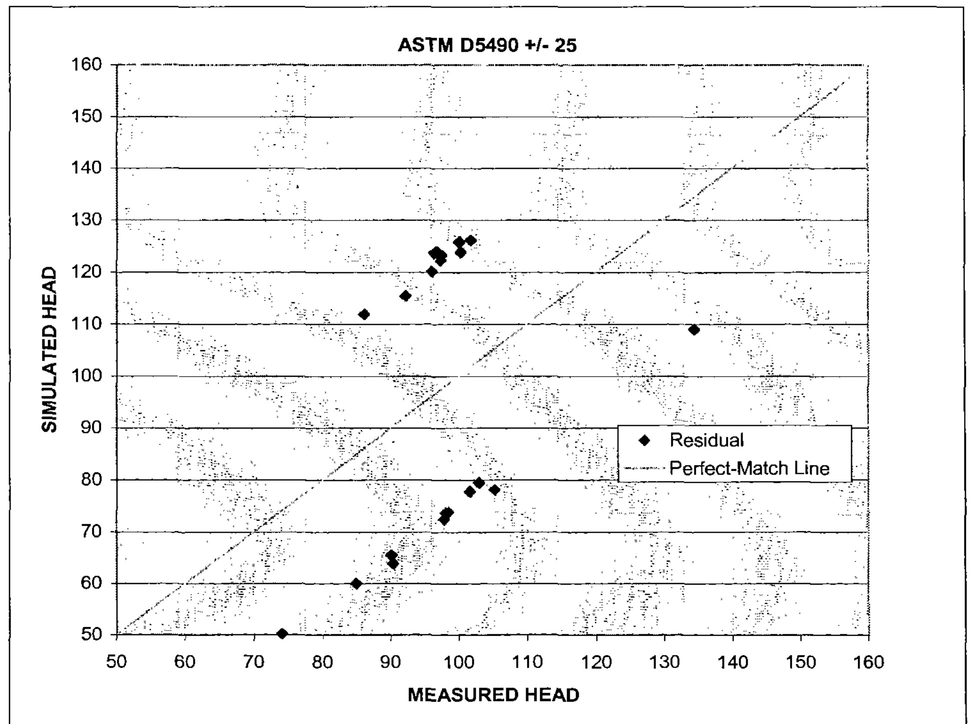
Well Name	X(Obs)	X^2	Y(Calc)	Y^2	XY	$(Y-X)^2$
MW-1	101.72	10346.96	126.11	15903.73	12827.91	594.87
MW-2	98.43	9688.46	73.77	5442.01	7261.18	608.12
MW-3	100.04	10008.00	125.80	15825.64	12585.03	663.58
MW-5	102.95	10598.70	79.45	6312.30	8179.38	552.25
MW-6	100.00	10000.00	125.66	15790.44	12566.00	658.44
MW-7	101.56	10314.43	77.80	6052.84	7901.37	564.54
MW-8	92.24	8508.22	115.42	13321.78	10646.34	537.31
MW-9	90.34	8161.32	63.77	4066.61	5760.98	705.96
MW-17	96.33	9279.47	123.62	15281.90	11908.31	744.74
MW-20	105.25	11077.56	78.10	6099.61	8220.03	737.12
MW-21	96.10	9235.21	120.11	14426.41	11542.57	576.48
MW-23	74.01	5477.48	50.21	2521.04	3716.04	566.44
MW-24	96.66	9343.16	123.96	15366.08	11981.97	745.29
MW-25	98.04	9611.84	73.71	5433.16	7226.53	591.95
MW-26	97.39	9484.81	123.21	15180.70	11999.42	666.67
MW-27	90.11	8119.81	65.48	4287.63	5900.40	606.64
MW-28	100.23	10046.05	123.76	15316.54	12404.46	553.66
MW-29	84.92	7211.41	59.98	3597.60	5093.50	622.00
MW-30	86.15	7421.82	111.88	12517.13	9638.46	662.03
MW-31	97.87	9578.54	72.38	5238.86	7083.83	649.74
MW-32	97.31	9469.24	122.17	14925.51	11888.36	618.02
MW-33	134.43	18071.42	108.96	11872.28	14647.49	648.72

Statistics

Sxy=		210979.58
Sx=		2142.08
Sx^2		211053.92
Sy=		2145.31
Sy^2		224779.83
$S(Y-X)^2$		13874.58
n=		22
XMin		74.01
XMax		134.43
SP =	Sxy-(Sx*Sy/n)	2096.60
COV=	SP/n-1	99.84
s_x^2=	^{2}]-$(Sx)^2$/n)/n-1	118.35
s_x=	SQRT(s_x^2)	10.88
s_y^2=	^{2}]-$(Sy)^2$/n)/n-1	741.99
s_y=	SQRT(s_y^2)	27.24
r=	COV/s_x*s_y	0.34
r^2=		0.11

Visual MODFLOW

RMS=	SQRT(S(Y-X)	25.1130
NRMS=	RMS/(Xmax-)	41.564%



Information from ASTM D5490 Fig. X1.2 plus 25

WELL	MEASURED HEAD	SIMULATED HEAD	RESIDUAL	RESIDUAL SQ
MW-1	101.72	126.11	24.39	594.8721
MW-2	98.43	123.77	25.34	642.1156
MW-3	100.04	125.80	25.76	663.5776
MW-5	*102.95*	*129.45*	*26.50*	*702.25*
MW-6	100.00	125.66	25.66	658.4356
MW-7	101.56	127.80	26.24	688.5376
MW-8	92.24	115.42	23.18	537.3124
MW-9	90.34	113.77	23.43	548.9649
MW-17	96.33	123.62	27.29	744.7441
MW-20	105.25	128.10	22.85	522.1225
MW-21	96.10	120.11	24.01	576.4801
MW-23	74.01	100.21	26.20	686.44
MW-24	96.66	123.96	27.30	745.29
MW-25	98.04	123.71	25.67	658.9489
MW-26	97.39	123.21	25.82	666.6724
MW-27	90.11	115.48	25.37	643.6369
MW-28	100.23	123.76	23.53	553.6609
MW-29	84.92	109.98	25.06	628.0036
MW-30	86.15	111.88	25.73	662.0329
MW-31	97.87	122.38	24.51	600.7401
MW-32	97.31	122.17	24.86	618.0196
MW-33	134.43	158.96	24.53	601.7209
	50.00	50.00		
	160.00	160.00		
MEAN	97.37	122.51		
VARIANCE	118.35	115.59		
RMS				25.17626832
NRMS				41.67%

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	22	2142.08	97.367273	118.3537732
Column 2	22	2695.31	122.51409	115.5893396

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6955.987111	1	6955.9871	59.46733827	1.42041E-09	4.0726604
Within Groups	4912.805368	42	116.97156			
Total	11868.79248	43				

Well Name	X(Obs)	X^2	Y(Calc)	Y^2	XY	$(Y-X)^2$
MW-1	101.72	10346.96	126.11	15903.73	12827.91	594.87
MW-2	98.43	9688.46	123.77	15319.01	12182.68	642.12
MW-3	100.04	10008.00	125.80	15825.64	12585.03	663.58
MW-5	*102.95*	*10598.70*	*129.45*	*16757.30*	*13326.66*	*702.25*
MW-6	100.00	10000.00	125.66	15790.44	12566.00	658.44
MW-7	101.56	10314.43	127.80	16332.84	12979.37	688.54
MW-8	92.24	8508.22	115.42	13321.78	10646.34	537.31
MW-9	90.34	8161.32	113.77	12943.61	10277.98	548.96
MW-17	96.33	9279.47	123.62	15281.90	11908.31	744.74
MW-20	105.25	11077.56	128.10	16409.61	13482.53	522.12
MW-21	96.10	9235.21	120.11	14426.41	11542.57	576.48
MW-23	74.01	5477.48	100.21	10042.04	7416.54	686.44
MW-24	96.66	9343.16	123.96	15366.08	11981.97	745.29
MW-25	98.04	9611.84	123.71	15304.16	12128.53	658.95
MW-26	97.39	9484.81	123.21	15180.70	11999.42	666.67
MW-27	90.11	8119.81	115.48	13335.63	10405.90	643.64
MW-28	100.23	10046.05	123.76	15316.54	12404.46	553.66
MW-29	84.92	7211.41	109.98	12095.60	9339.50	628.00
MW-30	86.15	7421.82	111.88	12517.13	9638.46	662.03
MW-31	97.87	9578.54	122.38	14976.86	11977.33	600.74
MW-32	97.31	9469.24	122.17	14925.51	11888.36	618.02
MW-33	134.43	18071.42	158.96	25268.28	21368.99	601.72

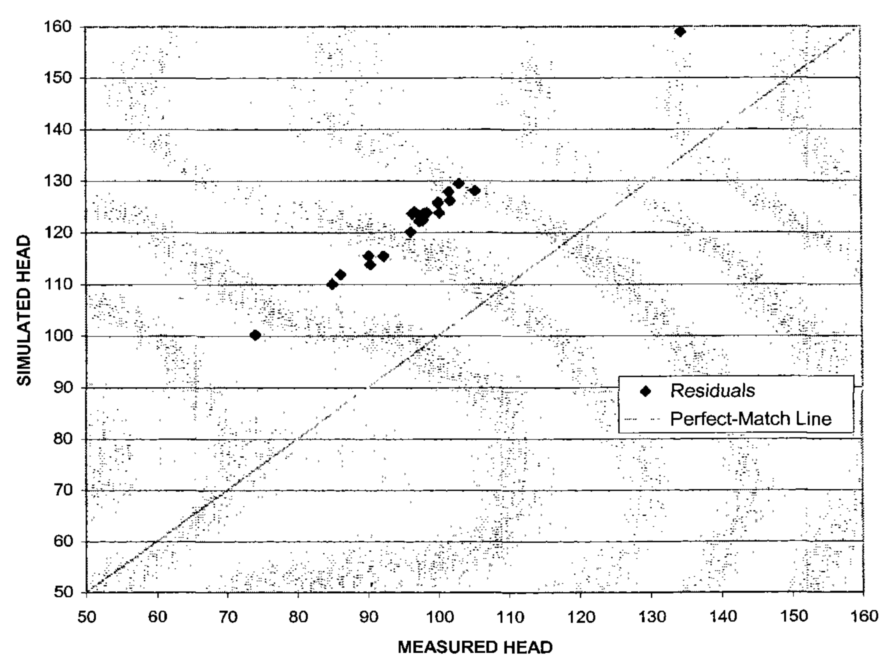
Statistics

Sxy=		264875.08
Sx=		2142.08
Sx^2		211053.92
Sy=		2695.31
Sy^2		*332640.83*
$S(Y-X)^2$		13944.58
n=		22
XMin		74.01
XMax		134.43
SP =	Sxy-(Sx*Sy/n)	2440.10
COV=	SP/n-1	116.20
$s_x^2=$	^{2}]-$(Sx)^2$/n)/n-1	118.35
$s_x=$	SQRT(s_x^2)	10.88
$s_y^2=$	^{2}]-$(Sy)^2$/n)/n-1	115.59
$s_y=$	SQRT(s_y^2)	10.75
r=	COV/s_x*s_y	0.99
r^2=		0.99

Visual MODFLOW

RMS=	SQRT(S(Y-X)	25.1763
NRMS=	RMS/(Xmax-)	41.669%

ASTM D5490 + 25



Information from A[illegible] D5490 Fig. X1.2 - Multiplied by a Factor to change the Gradient

WELL	MEASURED HEAD	SIMULATED HEAD	RESIDUAL	RESIDUAL SQ
MW-1	101.72	107.61	5.89	34.72708922
MW-2	98.43	102.69	4.26	18.14427287
MW-3	100.04	106.95	6.91	47.80485159
MW-5	102.95	114.84	11.89	141.3727258
MW-6	100.00	106.66	6.66	44.31853608
MW-7	101.56	111.24	9.68	93.71055176
MW-8	92.24	86.06	-6.18	38.1824606
MW-9	90.34	82.95	-7.39	54.63343196
MW-17	96.33	102.38	6.05	36.57759098
MW-20	105.25	111.89	6.64	44.09798777
MW-21	96.10	95.22	-0.88	0.774175848
MW-23	74.01	59.54	-14.47	209.306546
MW-24	96.66	103.09	6.43	41.28151774
MW-25	98.04	102.56	4.52	20.47458664
MW-26	97.39	101.53	4.14	17.12688602
MW-27	90.11	86.18	-3.93	15.48377766
MW-28	100.23	102.67	2.44	5.947827589
MW-29	84.92	76.02	-8.90	79.26614552
MW-30	86.15	79.45	-6.70	44.83579574
MW-31	97.87	99.82	1.95	3.801038667
MW-32	97.31	99.39	2.08	4.32460044
MW-33	134.43	188.90	54.47	2966.730458
	50.00	50.00		
	160.00	160.00		
MEAN	97.37	101.26		
VARIANCE	118.35	565.65		
RMS				13.42135824
NRMS				22.21%

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	22	2142.08	97.367273	118.3537732
Column 2	22	2227.63506	101.25614	565.6520616

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	166.3560893	1	166.35609	0.486417165	0.489372879	4.0726604
Within Groups	14364.12253	42	342.00292			
Total	14530.47862	43				

Well Name	X(Obs)	X^2	Y(Calc)	Y^2	XY	$(Y-X)^2$
MW-1	101.72	10346.96	107.61	11580.55	10946.39	34.73
MW-2	98.43	9688.46	102.69	10545.16	10107.74	18.14
MW-3	100.04	10008.00	106.95	11439.18	10699.69	47.80
MW-5	102.95	10598.70	114.84	13188.23	11822.78	141.37
MW-6	100.00	10000.00	106.66	11375.76	10665.72	44.32
MW-7	101.56	10314.43	111.24	12374.43	11297.58	93.71
MW-8	92.24	8508.22	86.06	7406.46	7938.25	38.18
MW-9	90.34	8161.32	82.95	6880.46	7493.57	54.63
MW-17	96.33	9279.47	102.38	10481.24	9862.07	36.58
MW-20	105.25	11077.56	111.89	12519.51	11776.49	44.10
MW-21	96.10	9235.21	95.22	9066.87	9150.65	0.77
MW-23	74.01	5477.48	59.54	3545.32	4406.75	209.31
MW-24	96.66	9343.16	103.09	10626.53	9964.20	41.28
MW-25	98.04	9611.84	102.56	10519.56	10055.46	20.47
MW-26	97.39	9484.81	101.53	10308.03	9887.86	17.13
MW-27	90.11	8119.81	86.18	7426.14	7765.23	15.48
MW-28	100.23	10046.05	102.67	10540.89	10290.50	5.95
MW-29	84.92	7211.41	76.02	5778.56	6455.35	79.27
MW-30	86.15	7421.82	79.45	6312.95	6844.97	44.84
MW-31	97.87	9578.54	99.82	9963.96	9769.35	3.80
MW-32	97.31	9469.24	99.39	9878.29	9671.60	4.32
MW-33	134.43	18071.42	188.90	35682.34	25393.52	2966.73

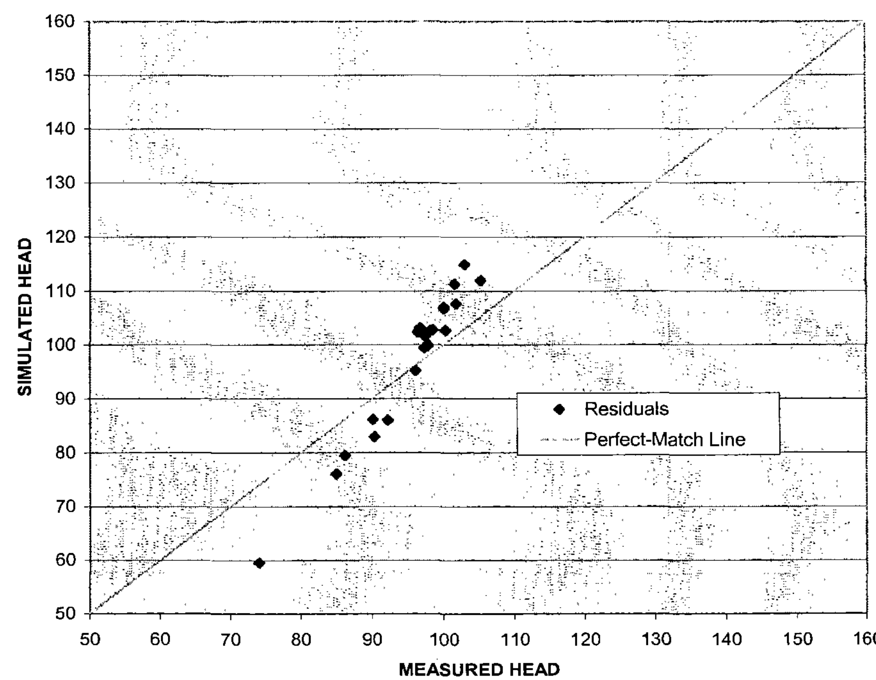
Statistics

Sxy=	222265.71
Sx=	2142.08
Sx^2	211053.92
Sy=	2227.63506
Sy^2	237440.42
$S(Y-X)^2$	3962.92
n=	22
XMin	74.01
XMax	134.43
SP = Sxy-(Sx*Sy/n)	5366.96
COV= SP/n-1	255.57
s_x^2= ^{2}]-(Sx)^2/n)/n-1	118.35
s_x= SQRT(s_x^2)	10.88
s_y^2= ^{2}]-(Sy)^2/n)/n-1	565.65
s_y= SQRT(s_y^2)	23.78
r= COV/s_x*s_y	0.99
r^2=	0.98

Visual MODFLOW

RMS= SQRT(S(Y-X)	13.4214
NRMS= RMS/(Xmax-)	22.213%

ASTM D5490 - Incorrect Gradient



The UNIVARIATE Procedure
Variable: obs

Normal Probability Plot

```
580.25+                                                  *
      |
      |                                             * * ++
578.75+                                           *  +++
      |                                        *** ++
      |                                     ****+++
577.25+                                  *** +++
      |                                   +++
      |                                ***
575.75+                             ++**
      |                          +++ **
      |                       +++****
574.25+                    +******
      |              ********
      |       *******+++
572.75+*  * *     +++
       +----+----+----+----+----+----+----+----+----+----+
           -2        -1         0        +1        +2
```

Normal scores = z-score

-- aa=1 --

The UNIVARIATE Procedure
Variable: obs

Normal Probability Plot

```
580.25+                                             *
      |
      |                                                 +
      |                                              +++
      |                                           +++
      |                                      * *++
      |                                  * *+++
576.75+                                  +++
      |                               +**
      |                            +++
      |                         +++  **
      |                      +++ ****
      |                   +++*****
      |              ********
573.25+    *    * * *+++
      +----+----+----+----+----+----+----+----+----+----+
          -2        -1         0        +1        +2
```

```
------------------------------------ aa=2 ------------------------------------------

                         The UNIVARIATE Procedure
                              Variable:  obs

          Stem Leaf                     #             Boxplot
           579 011                      3                0
           578 55                       2                |
           578                                           |
           577 5688                     4                |
           577 4                        1                |
           576                                           |
           576 013                      3                |
           575 778                      3             +-----+
           575 124                      3             |     |
           574 56677789                 8             |  +  |
           574 0011122233344           13             *-----*
           573 57788888999             11             +-----+
           573 0123444                  7                |
           572 79                       2                |
               ----+----+----+----+


                          Normal Probability Plot
        579.25+                                                *   * +
              |                                              *    +++
              |                                           * *  +++
              |                                        ***  +++
              |                                       ** +++
              |                                       +++
              |                                    +**
              |                                 ++***
              |                              +++ **
              |                           +++*****
              |                        +******
              |                   *******
              |             * ****++
        572.75+  *   * *  +++
               +----+----+----+----+----+----+----+----+----+----+
                   -2        -1         0        +1        +2
```

-- aa=3 --

The UNIVARIATE Procedure
Variable: obs

Quantiles (Definition 5)

Quantile	Estimate
90%	577.79
75% Q3	577.14
50% Median	574.69
25% Q1	573.81
10%	573.70
5%	573.48
1%	573.48
0% Min	573.48

Extreme Observations

-----Lowest-----		-----Highest----	
Value	Obs	Value	Obs
573.48	1	577.14	11
573.70	5	577.20	10
573.71	14	577.73	12
573.75	4	577.79	15
573.81	6	578.47	17

```
Stem Leaf                     #             Boxplot
 578 5                        1                |
 577 1278                     4             +-----+
 576 03                       2             |     |
 575 5                        1             |  +  |
 574 00359                    5             *-----*
 573 57788                    5             +-----+
     ----+----+----+----+
```

```
                        Normal Probability Plot
578.5+                                                    ++*+++
     |                                           ** +*+*++
     |                                        **++++
     |                                   +++++*+
     |                               +++*+** *
573.5+      *     *+*++** *
     +----+----+----+----+----+----+----+----+----+----+
         -2        -1         0        +1        +2
```

The UNIVARIATE Procedure
Variable: calc

Normal Probability Plot

```
579.75+                                                 *
      |                                            *  *
      |                                          *   ++++
      |                                           +++
      |                                     *****+
      |                                  ***+++
      |                                **+++
      |                               **+
      |                            ++**
      |                          +++ **
      |                       +++   **
      |                    *********
      |              *******
573.25+*  * * *******+++
       +----+----+----+----+----+----+----+----+----+----+
           -2        -1         0        +1        +2
```

```
---------------------------------------- aa=1 ----------------------------------------

                              The UNIVARIATE Procedure
                                Variable:  calc

                                 Normal Probability Plot
          579.75+                                                *
                |
                |                                                  +++
                |                                               +++
                |                                          *  *+++
                |                                        *  +++
                |                                     **+++
                |                                    *++
                |                                 +++
                |                              +++  **
                |                           +++    *
                |                        +++******
                |                    *******
          573.25+    *     *  *  *  **+
                 +----+----+----+----+----+----+----+----+----+----+
                     -2        -1         0         +1        +2
```

--------------------------------------- aa=2 ---------------------------------------

The UNIVARIATE Procedure
Variable: calc

```
                         Normal Probability Plot
579.25+                                                   *   *
       |                                                *     +++
       |                                                    +++
       |                                          *** *+++
       |                                       ** +++
       |                                      *+++
576.25+                                   +*+
       |                              +++ *
       |                          +++ ***
       |                      +++   **
       |                  **********
       |          *******
573.25+  *    * ** ****++
        +----+----+----+----+----+----+----+----+----+----+
            -2        -1         0        +1        +2
```

```
---------------------------------------- aa=3 ------------------------------------------

                          The UNIVARIATE Procedure
                              Variable:  calc

                          Normal Probability Plot
      577.75+                                              ++++*
             |                                      **   *+*
             |                                       +++
             |                                   **++
      575.75+                                   *++
             |                               ++++
             |                            +++    *
             |                      *   **+ * **
      573.75+                *    * +++
              +----+----+----+----+----+----+----+----+----+----+
                  -2        -1         0        +1        +2
```

The CORR Procedure

3 Variables: obs calc res

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
obs	109	574.97165	1.68150	574.32000	572.72000	580.13000
calc	109	574.90881	1.63324	574.13000	573.02000	579.90000
res	109	-0.06303	0.37709	-0.08000	-1.17000	1.04000

Pearson Correlation Coefficients, N = 109
Prob > |r| under H0: Rho=0

	obs	calc	res
obs	1.00000	0.97454 <.0001	-0.23838 0.0126
calc	0.97454 <.0001	1.00000	-0.01457 0.8805
res	-0.23838 0.0126	-0.01457 0.8805	1.00000

Spearman Correlation Coefficients, N = 109
Prob > |r| under H0: Rho=0

	obs	calc	res
obs	1.00000	0.87964 <.0001	-0.34880 0.0002
calc	0.87964 <.0001	1.00000	0.01840 0.8494
res	-0.34880 0.0002	0.01840 0.8494	1.00000

Scatter

-- aa=1 --

The CORR Procedure

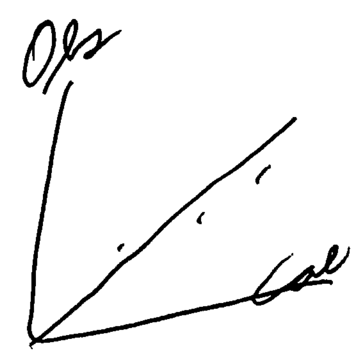
3 Variables: obs calc res

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
obs	31	574.84323	1.66927	574.21000	573.24000	580.13000
calc	31	574.75323	1.65852	574.08000	573.16000	579.90000
res	31	-0.09032	0.31288	-0.08000	-0.70000	0.48000

Pearson Correlation Coefficients, N = 31
Prob > |r| under H0: Rho=0

	obs	calc	res
obs	1.00000	0.98237	-0.12982
		<.0001	0.4864
calc	0.98237	1.00000	0.05780
	<.0001		0.7574
res	-0.12982	0.05780	1.00000
	0.4864	0.7574	



Spearman Correlation Coefficients, N = 31
Prob > |r| under H0: Rho=0

	obs	calc	res
obs	1.00000	0.93316	-0.20728
		<.0001	0.2632
calc	0.93316	1.00000	0.08994
	<.0001		0.6304
res	-0.20728	0.08994	1.00000
	0.2632	0.6304	

aa=2

The CORR Procedure

3 Variables: obs calc res

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
obs	60	574.92433	1.69547	574.30500	572.72000	579.12000
calc	60	574.86267	1.64991	574.13000	573.02000	579.18000
res	60	-0.06183	0.36150	-0.10000	-0.82000	0.79000

Pearson Correlation Coefficients, N = 60
Prob > |r| under H0: Rho=0

	obs	calc	res
obs	1.00000	0.97700	-0.23039
		<.0001	0.0766
calc	0.97700	1.00000	-0.01761
	<.0001		0.8937
res	-0.23039	~~-0.01761~~	1.00000
	0.0766	0.8937	

Spearman Correlation Coefficients, N = 60
Prob > |r| under H0: Rho=0

	obs	calc	res
obs	1.00000	0.88534	-0.38940
		<.0001	0.0021
calc	0.88534	1.00000	-0.04290
	<.0001		0.7448
res	-0.38940	-0.04290	1.00000
	0.0021	0.7448	

aa=3

The CORR Procedure

3 Variables: obs calc res

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
obs	18	575.35056	1.69666	574.69000	573.48000	578.47000
calc	18	575.33056	1.55063	574.34000	573.52000	577.60000
res	18	-0.02000	0.52319	0.01500	-1.17000	1.04000

Pearson Correlation Coefficients, N = 18
Prob > |r| under H0: Rho=0

	obs	calc	res
obs	1.00000	0.95203 <.0001	-0.42129 0.0817
calc	0.95203 <.0001	1.00000	-0.12356 0.6252
res	-0.42129 0.0817	-0.12356 0.6252	1.00000

Spearman Correlation Coefficients, N = 18
Prob > |r| under H0: Rho=0

	obs	calc	res
obs	1.00000	0.79608 <.0001	-0.44812 0.0622
calc	0.79608 <.0001	1.00000	-0.00103 0.9968
res	-0.44812 0.0622	-0.00103 0.9968	1.00000

The REG Procedure

Descriptive Statistics

Variable	Sum	Mean	Uncorrected SS	Variance	Standard Deviation
Intercept	109.00000	1.00000	109.00000	0	0
calc	62665	574.90881	36026983	2.66747	1.63324
obs	62672	574.97165	36034877	2.82744	1.68150

Correlation

Variable	calc	obs
calc	1.0000	0.9745
obs	0.9745	1.0000

Y = obs

Regression ANOVA

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	290.01289	290.01289	2021.48	<.0001
Error	107	15.35081	0.14347		
Corrected Total	108	305.36370			

Root MSE	0.37877	R-Square	0.9497
Dependent Mean	574.97165	Adj R-Sq	0.9493
Coeff Var	0.06588		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-1.85608	12.82960	-0.14	0.8852
calc	1	1.00334	0.02232	44.96	<.0001

Adjusted — calc.

ANOVA — 0-10 —
11-20 —
21-30 —

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Dep Var obs	Predicted Value	Std Error Mean Predict	95% CL Mean		95% CL Predict		Residual
1	576.2900	576.8391	0.0551	576.7297	576.9484	576.0803	577.5978	-0.5491
2	573.6900	574.1401	0.0407	574.0594	574.2208	573.3849	574.8953	-0.4501
3	574.0200	574.4110	0.0384	574.3349	574.4870	573.6563	575.1657	-0.3910
4	577.3300	577.7320	0.0713	577.5907	577.8734	576.9680	578.4961	-0.4020
5	574.7100	574.9829	0.0363	574.9110	575.0548	574.2286	575.7372	-0.2729
6	573.5100	573.7688	0.0451	573.6795	573.8582	573.0127	574.5250	-0.2588
7	573.5500	573.7989	0.0447	573.7104	573.8875	573.0429	574.5550	-0.2489
8	573.2700	573.4578	0.0495	573.3597	573.5559	572.7006	574.2151	-0.1878
9	573.5800	573.7688	0.0451	573.6795	573.8582	573.0127	574.5250	-0.1888
10	575.1500	575.2939	0.0370	575.2206	575.3672	574.5395	576.0484	-0.1439
11	577.5700	577.7019	0.0707	577.5617	577.8422	576.9381	578.4658	-0.1319
12	573.7200	573.8290	0.0443	573.7412	573.9169	573.0731	574.5850	-0.1090
13	576.1800	576.2772	0.0465	576.1851	576.3693	575.5207	577.0337	-0.0972
14	573.3400	573.3474	0.0512	573.2459	573.4489	572.5897	574.1051	-0.007441
15	575.3700	575.3742	0.0374	575.3001	575.4483	574.6197	576.1287	-0.004183
16	573.2400	573.2170	0.0533	573.1114	573.3226	572.4587	573.9753	0.0230
17	573.3600	573.3173	0.0517	573.2149	573.4198	572.5595	574.0752	0.0427
18	574.4300	574.3909	0.0385	574.3146	574.4673	573.6362	575.1456	0.0391
19	573.9500	573.8792	0.0437	573.7927	573.9658	573.1234	574.6350	0.0708
20	574.1400	574.0197	0.0420	573.9364	574.1029	573.2642	574.7751	0.1203
21	574.3200	574.2003	0.0401	574.1207	574.2798	573.4452	574.9553	0.1197
22	580.1300	579.9795	0.1171	579.7473	580.2117	579.1935	580.7655	0.1505
23	574.2100	574.0397	0.0418	573.9569	574.1226	573.2843	574.7952	0.1703
24	574.0400	573.8491	0.0440	573.7618	573.9364	573.0932	574.6050	0.1909
25	573.8800	573.5280	0.0484	573.4320	573.6241	572.7711	574.2850	0.3520
26	574.5100	574.1200	0.0409	574.0389	574.2011	573.3648	574.8752	0.3900
27	574.7900	574.3508	0.0388	574.2738	574.4277	573.5960	575.1056	0.4392
28	577.8500	577.3608	0.0643	577.2332	577.4883	576.5992	578.1224	0.4892
29	577.3500	576.8290	0.0550	576.7200	576.9380	576.0703	577.5878	0.5210
30	574.6900	574.1501	0.0406	574.0696	574.2306	573.3949	574.9053	0.5399
31	573.9700	573.3274	0.0515	573.2253	573.4295	572.5696	574.0852	0.6426
32	573.2300	574.0799	0.0413	573.9979	574.1618	573.3246	574.8352	-0.8499
33	573.5200	574.2705	0.0395	574.1922	574.3488	573.5156	575.0254	-0.7505
34	576.0900	576.8290	0.0550	576.7200	576.9380	576.0703	577.5878	-0.7390
35	573.3900	574.0999	0.0411	574.0184	574.1815	573.3447	574.8552	-0.7099
36	576.3400	576.9595	0.0572	576.8461	577.0728	576.2001	577.7188	-0.6195
37	573.7500	574.2404	0.0398	574.1616	574.3192	573.4854	574.9954	-0.4904
38	573.7000	574.1200	0.0409	574.0389	574.2011	573.3648	574.8752	-0.4200
39	572.7200	573.1468	0.0544	573.0389	573.2547	572.3882	573.9054	-0.4268
40	573.7500	574.1200	0.0409	574.0389	574.2011	573.3648	574.8752	-0.3700
41	576.0300	576.3876	0.0480	576.2923	576.4828	575.6307	577.1444	-0.3576
42	573.8000	574.1401	0.0407	574.0594	574.2208	573.3849	574.8953	-0.3401

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Std Error Residual	Student Residual	-2-1 0 1 2	Cook's D	RStudent	Hat Diag H	Cov Ratio	DFFITS
1	0.375	-1.465	**|	0.023	-1.4732	0.0212	0.9997	-0.2168
2	0.377	-1.195	**|	0.008	-1.1976	0.0116	1.0035	-0.1295
3	0.377	-1.038	**|	0.006	-1.0379	0.0103	1.0089	-0.1057
4	0.372	-1.081	**|	0.021	-1.0816	0.0354	1.0335	-0.2073
5	0.377	-0.724	*|	0.002	-0.7222	0.0092	1.0183	-0.0695
6	0.376	-0.688	*|	0.003	-0.6866	0.0142	1.0245	-0.0823
7	0.376	-0.662	*|	0.003	-0.6601	0.0139	1.0249	-0.0784
8	0.376	-0.500	*|	0.002	-0.4984	0.0171	1.0318	-0.0657
9	0.376	-0.502	*|	0.002	-0.5004	0.0142	1.0287	-0.0600
10	0.377	-0.382	|	0.001	-0.3803	0.0095	1.0260	-0.0373
11	0.372	-0.355	|	0.002	-0.3531	0.0349	1.0533	-0.0671
12	0.376	-0.290	|	0.001	-0.2886	0.0137	1.0315	-0.0340
13	0.376	-0.259	|	0.001	-0.2574	0.0151	1.0332	-0.0318
14	0.375	-0.0198	|	0.000	-0.0197	0.0183	1.0379	-0.0027
15	0.377	-0.0111	|	0.000	-0.0110	0.0097	1.0290	-0.0011
16	0.375	0.0613	|	0.000	0.0610	0.0198	1.0395	0.0087
17	0.375	0.114	|	0.000	0.1132	0.0186	1.0380	0.0156
18	0.377	0.104	|	0.000	0.1033	0.0103	1.0294	0.0106
19	0.376	0.188	|	0.000	0.1873	0.0133	1.0320	0.0217
20	0.376	0.320	|	0.001	0.3183	0.0123	1.0297	0.0355
21	0.377	0.318	|	0.001	0.3165	0.0112	1.0286	0.0337
22	0.360	0.418	|	0.009	0.4162	0.0956	1.1231	0.1354
23	0.376	0.452	|	0.001	0.4506	0.0122	1.0276	0.0500
24	0.376	0.507	|*	0.002	0.5056	0.0135	1.0280	0.0592
25	0.376	0.937	|*	0.007	0.9364	0.0164	1.0190	0.1208
26	0.377	1.036	|**	0.006	1.0360	0.0117	1.0104	0.1126
27	0.377	1.166	|**	0.007	1.1677	0.0105	1.0038	0.1203
28	0.373	1.311	|**	0.026	1.3151	0.0289	1.0158	0.2267
29	0.375	1.390	|**	0.021	1.3963	0.0211	1.0036	0.2049
30	0.377	1.434	|**	0.012	1.4408	0.0115	0.9916	0.1554
31	0.375	1.713	|***	0.028	1.7284	0.0185	0.9820	0.2373
32	0.377	-2.257	****|	0.031	-2.3022	0.0119	0.9354	-0.2528
33	0.377	-1.992	***|	0.022	-2.0208	0.0109	0.9551	-0.2118
34	0.375	-1.972	***|	0.042	-1.9994	0.0211	0.9666	-0.2933
35	0.377	-1.886	***|	0.021	-1.9086	0.0118	0.9637	-0.2085
36	0.374	-1.654	***|	0.032	-1.6681	0.0228	0.9901	-0.2548
37	0.377	-1.302	**|	0.009	-1.3062	0.0110	0.9979	-0.1379
38	0.377	-1.115	**|	0.007	-1.1167	0.0117	1.0072	-0.1214
39	0.375	-1.139	**|	0.014	-1.1402	0.0207	1.0154	-0.1656
40	0.377	-0.983	*|	0.006	-0.9825	0.0117	1.0125	-0.1068
41	0.376	-0.952	*|	0.007	-0.9513	0.0161	1.0182	-0.1216
42	0.377	-0.903	*|	0.005	-0.9023	0.0116	1.0152	-0.0976

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

	-------DFBETAS-------	
Obs	Intercept	calc
1	0.1629	-0.1633
2	-0.0591	0.0588
3	-0.0346	0.0343
4	0.1782	-0.1785
5	0.0003	-0.0005
6	-0.0490	0.0488
7	-0.0460	0.0458
8	-0.0448	0.0447
9	-0.0357	0.0356
10	0.0071	-0.0072
11	0.0575	-0.0576
12	-0.0196	0.0195
13	0.0198	-0.0199
14	-0.0019	0.0019
15	0.0003	-0.0003
16	0.0064	-0.0064
17	0.0111	-0.0111
18	0.0036	-0.0035
19	0.0121	-0.0121
20	0.0180	-0.0179
21	0.0145	-0.0144
22	-0.1286	0.1287
23	0.0249	-0.0248
24	0.0337	-0.0336
25	0.0803	-0.0800
26	0.0524	-0.0521
27	0.0431	-0.0428
28	-0.1869	0.1872
29	-0.1535	0.1539
30	0.0703	-0.0699
31	0.1689	-0.1684
32	-0.1219	0.1213
33	-0.0842	0.0837
34	0.2199	-0.2204
35	-0.0988	0.0983
36	0.1965	-0.1970
37	-0.0568	0.0564
38	-0.0565	0.0562
39	-0.1238	0.1235
40	-0.0497	0.0494
41	0.0795	-0.0797
42	-0.0446	0.0443

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Dep Var obs	Predicted Value	Std Error Mean Predict	95% CL Mean		95% CL Predict		Residual
43	578.9500	579.2571	0.1020	579.0549	579.4593	578.4795	580.0347	-0.3071
44	573.8900	574.1702	0.0404	574.0900	574.2503	573.4150	574.9253	-0.2802
45	573.7900	574.0598	0.0416	573.9774	574.1422	573.3044	574.8152	-0.2698
46	573.0800	573.3474	0.0512	573.2459	573.4489	572.5897	574.1051	-0.2674
47	573.7400	573.9896	0.0423	573.9056	574.0735	573.2340	574.7451	-0.2496
48	577.7900	578.0330	0.0772	577.8801	578.1860	577.2667	578.7993	-0.2430
49	574.1200	574.2906	0.0393	574.2126	574.3685	573.5357	575.0455	-0.1706
50	574.0000	574.1601	0.0405	574.0798	574.2405	573.4050	574.9153	-0.1601
51	572.9200	573.0765	0.0556	572.9663	573.1868	572.3176	573.8355	-0.1565
52	572.9800	573.1367	0.0546	573.0285	573.2450	572.3781	573.8954	-0.1567
53	575.1500	575.2939	0.0370	575.2206	575.3672	574.5395	576.0484	-0.1439
54	573.3900	573.5180	0.0486	573.4217	573.6143	572.7610	574.2750	-0.1280
55	573.3400	573.4377	0.0498	573.3390	573.5365	572.6804	574.1951	-0.0977
56	577.7700	577.8625	0.0738	577.7161	578.0088	577.0975	578.6275	-0.0925
57	579.0900	579.1367	0.0995	578.9395	579.3339	578.3604	579.9130	-0.0467
58	573.8800	573.8692	0.0438	573.7824	573.9560	573.1133	574.6250	0.0108
59	574.6600	574.6518	0.0370	574.5785	574.7251	573.8973	575.4062	0.008220
60	573.8300	573.7789	0.0449	573.6898	573.8680	573.0227	574.5350	0.0511
61	577.4600	577.4009	0.0651	577.2719	577.5299	576.6391	578.1628	0.0591
62	574.2900	574.1902	0.0402	574.1105	574.2700	573.4352	574.9453	0.0998
63	574.1300	573.9996	0.0422	573.9159	574.0833	573.2441	574.7551	0.1304
64	574.3200	574.1902	0.0402	574.1105	574.2700	573.4352	574.9453	0.1298
65	574.2500	574.1200	0.0409	574.0389	574.2011	573.3648	574.8752	0.1300
66	575.6900	575.5648	0.0386	575.4883	575.6413	574.8101	576.3196	0.1252
67	574.3900	574.2605	0.0396	574.1820	574.3389	573.5055	575.0154	0.1295
68	573.4000	573.2571	0.0526	573.1528	573.3615	572.4991	574.0152	0.1429
69	579.1200	578.9762	0.0962	578.7855	579.1668	578.2015	579.7509	0.1438
70	574.5900	574.3909	0.0385	574.3146	574.4673	573.6362	575.1456	0.1991
71	574.1300	573.8993	0.0434	573.8132	573.9853	573.1435	574.6551	0.2307
72	574.5300	574.2805	0.0394	574.2024	574.3587	573.5256	575.0355	0.2495
73	575.6600	575.4143	0.0376	575.3398	575.4888	574.6598	576.1689	0.2457
74	574.2900	574.0297	0.0419	573.9467	574.1128	573.2743	574.7852	0.2603
75	573.9700	573.6986	0.0460	573.6074	573.7898	572.9422	574.4550	0.2714
76	577.4000	577.1300	0.0602	577.0107	577.2493	576.3697	577.8903	0.2700
77	574.9400	574.6317	0.0371	574.5582	574.7052	573.8773	575.3862	0.3083
78	575.7900	575.4846	0.0380	575.4092	575.5599	574.7299	576.2392	0.3054
79	574.3500	574.0197	0.0420	573.9364	574.1029	573.2642	574.7751	0.3303
80	574.1800	573.8290	0.0443	573.7412	573.9169	573.0731	574.5850	0.3510
81	574.1600	573.7889	0.0448	573.7001	573.8777	573.0328	574.5450	0.3711
82	574.7800	574.3508	0.0388	574.2738	574.4277	573.5960	575.1056	0.4292
83	574.6500	574.2103	0.0400	574.1309	574.2897	573.4553	574.9654	0.4397
84	573.9000	573.4578	0.0495	573.3597	573.5559	572.7006	574.2151	0.4422

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

```
        Std Error  Student                       Cook's              Hat Diag      Cov
 Obs     Residual Residual   -2-1 0 1 2               D  RStudent          H     Ratio    DFFITS

  43        0.365   -0.842 |      *|      |       0.028   -0.8407     0.0725    1.0841   -0.2351
  44        0.377   -0.744 |      *|      |       0.003   -0.7424     0.0114    1.0201   -0.0797
  45        0.376   -0.717 |      *|      |       0.003   -0.7150     0.0120    1.0215   -0.0789
  46        0.375   -0.713 |      *|      |       0.005   -0.7110     0.0183    1.0281   -0.0970
  47        0.376   -0.663 |      *|      |       0.003   -0.6613     0.0125    1.0234   -0.0744
  48        0.371   -0.655 |      *|      |       0.009   -0.6536     0.0415    1.0545   -0.1360
  49        0.377   -0.453 |       |      |       0.001   -0.4511     0.0108    1.0261   -0.0471
  50        0.377   -0.425 |       |      |       0.001   -0.4236     0.0114    1.0273   -0.0456
  51        0.375   -0.418 |       |      |       0.002   -0.4162     0.0216    1.0380   -0.0618
  52        0.375   -0.418 |       |      |       0.002   -0.4166     0.0208    1.0372   -0.0607
  53        0.377   -0.382 |       |      |       0.001   -0.3803     0.0095    1.0260   -0.0373
  54        0.376   -0.341 |       |      |       0.001   -0.3394     0.0165    1.0338   -0.0439
  55        0.375   -0.260 |       |      |       0.001   -0.2592     0.0173    1.0356   -0.0344
  56        0.372   -0.249 |       |      |       0.001   -0.2478     0.0380    1.0580   -0.0492
  57        0.365   -0.128 |       |      |       0.001   -0.1272     0.0690    1.0941   -0.0346
  58        0.376   0.0288 |       |      |       0.000    0.0286     0.0134    1.0327    0.0033
  59        0.377   0.0218 |       |      |       0.000    0.0217     0.0095    1.0287    0.0021
  60        0.376    0.136 |       |      |       0.000    0.1353     0.0141    1.0332    0.0162
  61        0.373    0.158 |       |      |       0.000    0.1576     0.0295    1.0495    0.0275
  62        0.377    0.265 |       |      |       0.000    0.2637     0.0113    1.0292    0.0282
  63        0.376    0.346 |       |      |       0.001    0.3450     0.0124    1.0295    0.0387
  64        0.377    0.345 |       |      |       0.001    0.3431     0.0113    1.0283    0.0366
  65        0.377    0.345 |       |      |       0.001    0.3438     0.0117    1.0287    0.0374
  66        0.377    0.332 |       |      |       0.001    0.3308     0.0104    1.0275    0.0339
  67        0.377    0.344 |       |      |       0.001    0.3424     0.0109    1.0279    0.0360
  68        0.375    0.381 |       |      |       0.001    0.3793     0.0193    1.0362    0.0532
  69        0.366    0.393 |       |      |       0.005    0.3911     0.0645    1.0860    0.1027
  70        0.377    0.528 |       |*     |       0.001    0.5266     0.0103    1.0242    0.0538
  71        0.376    0.613 |       |*     |       0.003    0.6114     0.0131    1.0253    0.0705
  72        0.377    0.662 |       |*     |       0.002    0.6604     0.0108    1.0217    0.0691
  73        0.377    0.652 |       |*     |       0.002    0.6501     0.0098    1.0209    0.0648
  74        0.376    0.691 |       |*     |       0.003    0.6897     0.0122    1.0224    0.0768
  75        0.376    0.722 |       |*     |       0.004    0.7202     0.0148    1.0242    0.0882
  76        0.374    0.722 |       |*     |       0.007    0.7203     0.0252    1.0352    0.1159
  77        0.377    0.818 |       |*     |       0.003    0.8166     0.0096    1.0160    0.0803
  78        0.377    0.811 |       |*     |       0.003    0.8092     0.0101    1.0167    0.0817
  79        0.376    0.878 |       |*     |       0.005    0.8766     0.0123    1.0169    0.0978
  80        0.376    0.933 |       |*     |       0.006    0.9324     0.0137    1.0163    0.1098
  81        0.376    0.987 |       |*     |       0.007    0.9865     0.0140    1.0147    0.1175
  82        0.377    1.139 |       |**    |       0.007    1.1408     0.0105    1.0049    0.1175
  83        0.377    1.167 |       |**    |       0.008    1.1694     0.0112    1.0044    0.1243
  84        0.376    1.178 |       |**    |       0.012    1.1797     0.0171    1.0100    0.1555
```

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

	-------DFBETAS-------	
Obs	Intercept	calc
43	0.2194	-0.2197
44	-0.0353	0.0351
45	-0.0387	0.0385
46	-0.0686	0.0684
47	-0.0386	0.0384
48	0.1198	-0.1200
49	-0.0183	0.0181
50	-0.0204	0.0203
51	-0.0469	0.0468
52	-0.0455	0.0454
53	0.0071	-0.0072
54	-0.0293	0.0292
55	-0.0236	0.0235
56	0.0428	-0.0429
57	0.0322	-0.0322
58	0.0019	-0.0019
59	0.0004	-0.0004
60	0.0096	-0.0095
61	-0.0228	0.0228
62	0.0122	-0.0122
63	0.0199	-0.0198
64	0.0159	-0.0158
65	0.0174	-0.0173
66	-0.0115	0.0116
67	0.0145	-0.0144
68	0.0387	-0.0386
69	-0.0950	0.0951
70	0.0182	-0.0181
71	0.0389	-0.0388
72	0.0271	-0.0269
73	-0.0168	0.0170
74	0.0386	-0.0384
75	0.0544	-0.0542
76	-0.0923	0.0925
77	0.0166	-0.0164
78	-0.0243	0.0245
79	0.0495	-0.0493
80	0.0632	-0.0630
81	0.0693	-0.0690
82	0.0421	-0.0418
83	0.0529	-0.0526
84	0.1061	-0.1058

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Dep Var obs	Predicted Value	Std Error Mean Predict	95% CL Mean		95% CL Predict		Residual
85	578.4800	578.0230	0.0770	577.8704	578.1755	577.2568	578.7892	0.4570
86	575.1000	574.5815	0.0373	574.5076	574.6555	573.8270	575.3360	0.5185
87	574.6700	574.0899	0.0412	574.0082	574.1717	573.3346	574.8452	0.5801
88	574.7300	574.1501	0.0406	574.0696	574.2306	573.3949	574.9053	0.5799
89	578.4700	577.7220	0.0711	577.5810	577.8630	576.9580	578.4860	0.7480
90	575.3900	575.3742	0.0374	575.3001	575.4483	574.6197	576.1287	0.0158
91	577.5600	577.5414	0.0677	577.4072	577.6756	576.7786	578.3042	0.0186
92	573.4800	574.5815	0.0373	574.5076	574.6555	573.8270	575.3360	-1.1015
93	576.0300	576.5481	0.0505	576.4481	576.6481	575.7906	577.3056	-0.5181
94	575.5300	576.0063	0.0430	575.9211	576.0915	575.2506	576.7620	-0.4763
95	573.7500	574.1601	0.0405	574.0798	574.2405	573.4050	574.9153	-0.4101
96	573.7000	574.0899	0.0412	574.0082	574.1717	573.3346	574.8452	-0.3899
97	573.8100	574.2003	0.0401	574.1207	574.2798	573.4452	574.9553	-0.3903
98	576.3000	576.5280	0.0501	576.4286	576.6274	575.7706	577.2854	-0.2280
99	573.9600	574.1100	0.0410	574.0286	574.1913	573.3547	574.8652	-0.1500
100	574.0300	574.1200	0.0409	574.0389	574.2011	573.3648	574.8752	-0.0900
101	577.2000	577.2705	0.0627	577.1462	577.3948	576.5094	578.0316	-0.0705
102	577.1400	577.0899	0.0595	576.9720	577.2078	576.3298	577.8500	0.0501
103	577.7300	577.6718	0.0702	577.5327	577.8109	576.9082	578.4355	0.0582
104	574.3000	574.2203	0.0399	574.1412	574.2995	573.4653	574.9754	0.0797
105	573.7100	573.5782	0.0477	573.4836	573.6728	572.8214	574.3350	0.1318
106	577.7900	577.5414	0.0677	577.4072	577.6756	576.7786	578.3042	0.2486
107	574.5000	574.1200	0.0409	574.0389	574.2011	573.3648	574.8752	0.3800
108	578.4700	577.5013	0.0669	577.3685	577.6340	576.7388	578.2638	0.9687
109	574.8800	573.7688	0.0451	573.6795	573.8582	573.0127	574.5250	1.1112

Output Statistics

<table>
<tr><th>Obs</th><th>Std Error Residual</th><th>Student Residual</th><th>-2-1 0 1 2</th><th>Cook's D</th><th>RStudent</th><th>Hat Diag H</th><th>Cov Ratio</th><th>DFFITS</th></tr>
<tr><td>85</td><td>0.371</td><td>1.232</td><td>| |** |</td><td>0.033</td><td>1.2353</td><td>0.0413</td><td>1.0329</td><td>0.2563</td></tr>
<tr><td>86</td><td>0.377</td><td>1.375</td><td>| |** |</td><td>0.009</td><td>1.3813</td><td>0.0097</td><td>0.9929</td><td>0.1367</td></tr>
<tr><td>87</td><td>0.377</td><td>1.541</td><td>| |*** |</td><td>0.014</td><td>1.5508</td><td>0.0119</td><td>0.9859</td><td>0.1699</td></tr>
<tr><td>88</td><td>0.377</td><td>1.540</td><td>| |*** |</td><td>0.014</td><td>1.5499</td><td>0.0115</td><td>0.9856</td><td>0.1672</td></tr>
<tr><td>89</td><td>0.372</td><td>2.011</td><td>| |**** |</td><td>0.074</td><td>2.0401</td><td>0.0353</td><td>0.9779</td><td>0.3900</td></tr>
<tr><td>90</td><td>0.377</td><td>0.0420</td><td>| | |</td><td>0.000</td><td>0.0418</td><td>0.0097</td><td>1.0289</td><td>0.0041</td></tr>
<tr><td>91</td><td>0.373</td><td>0.0499</td><td>| | |</td><td>0.000</td><td>0.0497</td><td>0.0319</td><td>1.0525</td><td>0.0090</td></tr>
<tr><td>92</td><td>0.377</td><td>-2.922</td><td>| *****| |</td><td>0.042</td><td>-3.0323</td><td>0.0097</td><td>0.8712</td><td>-0.3001</td></tr>
<tr><td>93</td><td>0.375</td><td>-1.380</td><td>| **| |</td><td>0.017</td><td>-1.3861</td><td>0.0177</td><td>1.0008</td><td>-0.1863</td></tr>
<tr><td>94</td><td>0.376</td><td>-1.266</td><td>| **| |</td><td>0.010</td><td>-1.2692</td><td>0.0129</td><td>1.0016</td><td>-0.1449</td></tr>
<tr><td>95</td><td>0.377</td><td>-1.089</td><td>| **| |</td><td>0.007</td><td>-1.0900</td><td>0.0114</td><td>1.0080</td><td>-0.1173</td></tr>
</table>

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Std Error Residual	Student Residual	-2-1 0 1 2	Cook's D	RStudent	Hat Diag H	Cov Ratio	DFFITS
96	0.377	-1.036	| **| |	0.006	-1.0359	0.0119	1.0106	-0.1135
97	0.377	-1.036	| **| |	0.006	-1.0366	0.0112	1.0099	-0.1105
98	0.375	-0.607	| *| |	0.003	-0.6056	0.0175	1.0300	-0.0809
99	0.377	-0.398	| | |	0.001	-0.3967	0.0117	1.0280	-0.0432
100	0.377	-0.239	| | |	0.000	-0.2380	0.0117	1.0299	-0.0259
101	0.374	-0.189	| | |	0.001	-0.1879	0.0274	1.0470	-0.0315
102	0.374	0.134	| | |	0.000	0.1333	0.0246	1.0444	0.0212
103	0.372	0.156	| | |	0.000	0.1556	0.0343	1.0547	0.0293
104	0.377	0.211	| | |	0.000	0.2105	0.0111	1.0296	0.0223
105	0.376	0.351	| | |	0.001	0.3493	0.0159	1.0330	0.0444
106	0.373	0.667	| |* |	0.007	0.6654	0.0319	1.0438	0.1209
107	0.377	1.009	| |** |	0.006	1.0092	0.0117	1.0115	0.1097
108	0.373	2.599	| |***** |	0.109	2.6720	0.0312	0.9233	0.4798
109	0.376	2.955	| |***** |	0.063	3.0686	0.0142	0.8718	0.3678

Output Statistics

	-------DFBETAS-------	
Obs	Intercept	calc
85	-0.2257	0.2260
86	0.0322	-0.0318
87	0.0812	-0.0808
88	0.0756	-0.0752
89	-0.3349	0.3354
90	-0.0010	0.0010
91	-0.0076	0.0076
92	-0.0706	0.0698
93	0.1291	-0.1295
94	0.0773	-0.0776
95	-0.0525	0.0522
96	-0.0542	0.0540
97	-0.0475	0.0472
98	0.0557	-0.0558
99	-0.0203	0.0202
100	-0.0120	0.0120
101	0.0257	-0.0257
102	-0.0168	0.0168
103	-0.0251	0.0251
104	0.0094	-0.0093
105	0.0289	-0.0288
106	-0.1019	0.1020

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

	-------DFBETAS-------	
Obs	Intercept	calc
107	0.0510	-0.0508
108	-0.4025	0.4033
109	0.2191	-0.2183

Sum of Residuals	-4.8106E-11
Sum of Squared Residuals	15.35081
Predicted Residual SS (PRESS)	15.89632

-- aa=1 --

The REG Procedure

Descriptive Statistics

Variable	Sum	Mean	Uncorrected SS	Variance	Standard Deviation
Intercept	31.00000	1.00000	31.00000	0	0
calc	17817	574.75323	10240662	2.75068	1.65852
obs	17820	574.84323	10243870	2.78647	1.66927

Correlation

Variable	calc	obs
calc	1.0000	0.9824
obs	0.9824	1.0000

Y = obs

-- aa=1 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	80.67313	80.67313	800.95	<.0001
Error	29	2.92095	0.10072		
Corrected Total	30	83.59408			

Root MSE	0.31737	R-Square	0.9651
Dependent Mean	574.84323	Adj R-Sq	0.9639
Coeff Var	0.05521		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	6.55909	20.08009	0.33	0.7463
calc	1	0.98874	0.03494	28.30	<.0001

-- aa=1 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Dep Var obs	Predicted Value	Std Error Mean Predict	95% CL Mean		95% CL Predict		Residual
1	576.2900	576.8373	0.0906	576.6519	577.0227	576.1623	577.5123	-0.5473
2	573.6900	574.1776	0.0617	574.0515	574.3037	573.5163	574.8388	-0.4876
3	574.0200	574.4445	0.0587	574.3245	574.5646	573.7844	575.1046	-0.4245
4	577.3300	577.7173	0.1165	577.4791	577.9555	577.0259	578.4087	-0.3873
5	574.7100	575.0081	0.0573	574.8909	575.1253	574.3485	575.6677	-0.2981
6	573.5100	573.8117	0.0677	573.6734	573.9501	573.1481	574.4754	-0.3017
7	573.5500	573.8414	0.0671	573.7042	573.9786	573.1780	574.5048	-0.2914
8	573.2700	573.5052	0.0741	573.3538	573.6567	572.8387	574.1718	-0.2352
9	573.5800	573.8117	0.0677	573.6734	573.9501	573.1481	574.4754	-0.2317
10	575.1500	575.3146	0.0594	575.1932	575.4361	574.6543	575.9750	-0.1646
11	577.5700	577.6876	0.1155	577.4513	577.9239	576.9969	578.3784	-0.1176
12	573.7200	573.8711	0.0666	573.7350	574.0072	573.2079	574.5343	-0.1511
13	576.1800	576.2836	0.0764	576.1273	576.4399	575.6160	576.9512	-0.1036
14	573.3400	573.3965	0.0766	573.2399	573.5531	572.7288	574.0642	-0.0565
15	575.3700	575.3937	0.0602	575.2706	575.5169	574.7331	576.0544	-0.0237
16	573.2400	573.2679	0.0797	573.1050	573.4309	572.5987	573.9372	-0.0279
17	573.3600	573.3668	0.0773	573.2088	573.5248	572.6988	574.0349	-0.006807
18	574.4300	574.4248	0.0589	574.3043	574.5452	573.7646	575.0849	0.005236
19	573.9500	573.9205	0.0657	573.7862	574.0548	573.2577	574.5833	0.0295
20	574.1400	574.0589	0.0634	573.9293	574.1886	573.3970	574.7208	0.0811
21	574.3200	574.2369	0.0609	574.1124	574.3614	573.5760	574.8978	0.0831
22	580.1300	579.9321	0.1886	579.5463	580.3179	579.1770	580.6872	0.1979
23	574.2100	574.0787	0.0631	573.9497	574.2077	573.4169	574.7405	0.1313
24	574.0400	573.8908	0.0662	573.7555	574.0262	573.2278	574.5539	0.1492
25	573.8800	573.5744	0.0725	573.4261	573.7228	572.9086	574.2403	0.3056
26	574.5100	574.1578	0.0619	574.0311	574.2845	573.4965	574.8191	0.3522
27	574.7900	574.3852	0.0593	574.2640	574.5064	573.7249	575.0455	0.4048
28	577.8500	577.3514	0.1054	577.1359	577.5670	576.6675	578.0354	0.4986
29	577.3500	576.8274	0.0904	576.6426	577.0122	576.1525	577.5023	0.5226
30	574.6900	574.1875	0.0615	574.0616	574.3133	573.5263	574.8486	0.5025
31	573.9700	573.3767	0.0770	573.2191	573.5342	572.7088	574.0446	0.5933

Output Statistics

Obs	Std Error Residual	Student Residual	-2-1 0 1 2	Cook's D	RStudent	Hat Diag H	Cov Ratio	DFFITS
1	0.304	-1.799	| ***| |	0.144	-1.8760	0.0815	0.9217	-0.5590
2	0.311	-1.566	| ***| |	0.048	-1.6084	0.0378	0.9342	-0.3186
3	0.312	-1.361	| **| |	0.033	-1.3824	0.0342	0.9733	-0.2602
4	0.295	-1.312	| **| |	0.134	-1.3290	0.1346	1.0969	-0.5243

-- aa=1 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Std Error Residual	Student Residual	-2-1 0 1 2	Cook's D	RStudent	Hat Diag H	Cov Ratio	DFFITS
5	0.312	-0.955	*|	0.015	-0.9536	0.0326	1.0402	-0.1750
6	0.310	-0.973	*|	0.023	-0.9722	0.0454	1.0516	-0.2121
7	0.310	-0.939	*|	0.021	-0.9375	0.0447	1.0556	-0.2028
8	0.309	-0.762	*|	0.017	-0.7566	0.0544	1.0895	-0.1816
9	0.310	-0.747	*|	0.013	-0.7416	0.0454	1.0809	-0.1618
10	0.312	-0.528	*|	0.005	-0.5214	0.0350	1.0903	-0.0993
11	0.296	-0.398	|	0.012	-0.3921	0.1325	1.2231	-0.1533
12	0.310	-0.487	|	0.005	-0.4803	0.0440	1.1038	-0.1030
13	0.308	-0.336	|	0.003	-0.3311	0.0580	1.1299	-0.0821
14	0.308	-0.183	|	0.001	-0.1803	0.0582	1.1364	-0.0448
15	0.312	-0.0762	|	0.000	-0.0748	0.0360	1.1123	-0.0145
16	0.307	-0.0909	|	0.000	-0.0894	0.0630	1.1442	-0.0232
17	0.308	-0.0221	|	0.000	-0.0217	0.0593	1.1403	-0.0055
18	0.312	0.0168	|	0.000	0.0165	0.0344	1.1109	0.0031
19	0.310	0.0950	|	0.000	0.0934	0.0428	1.1200	0.0197
20	0.311	0.261	|	0.001	0.2565	0.0399	1.1120	0.0523
21	0.311	0.267	|	0.001	0.2625	0.0368	1.1082	0.0513
22	0.255	0.776	|*	0.164	0.7700	0.3533	1.5906	0.5691
23	0.311	0.422	|	0.004	0.4161	0.0395	1.1031	0.0844
24	0.310	0.481	|	0.005	0.4741	0.0435	1.1037	0.1011
25	0.309	0.989	|*	0.027	0.9886	0.0522	1.0567	0.2320
26	0.311	1.131	|**	0.025	1.1372	0.0381	1.0189	0.2263
27	0.312	1.298	|**	0.030	1.3145	0.0349	0.9860	0.2498
28	0.299	1.665	|***	0.172	1.7208	0.1102	0.9860	0.6057
29	0.304	1.718	|***	0.130	1.7809	0.0811	0.9419	0.5289
30	0.311	1.614	|***	0.051	1.6624	0.0376	0.9233	0.3285
31	0.308	1.927	|***	0.116	2.0279	0.0589	0.8666	0.5074

Output Statistics

	-------DFBETAS-------	
Obs	Intercept	calc
1	0.4336	-0.4346
2	-0.1224	0.1215
3	-0.0632	0.0624
4	0.4564	-0.4572
5	0.0173	-0.0178
6	-0.1148	0.1143
7	-0.1075	0.1070
8	-0.1163	0.1159

-- aa=1 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

	-------DFBETAS-------	
Obs	Intercept	calc
9	-0.0876	0.0872
10	0.0276	-0.0279
11	0.1331	-0.1333
12	-0.0534	0.0532
13	0.0545	-0.0547
14	-0.0300	0.0299
15	0.0046	-0.0047
16	-0.0162	0.0162
17	-0.0037	0.0037
18	0.0008	-0.0008
19	0.0099	-0.0098
20	0.0230	-0.0229
21	0.0182	-0.0181
22	-0.5420	0.5425
23	0.0364	-0.0361
24	0.0516	-0.0514
25	0.1440	-0.1434
26	0.0891	-0.0885
27	0.0689	-0.0682
28	-0.5085	0.5094
29	-0.4095	0.4104
30	0.1246	-0.1237
31	0.3424	-0.3413

Sum of Residuals	-7.3834E-12
Sum of Squared Residuals	2.92095
Predicted Residual SS (PRESS)	3.37744

-- aa=2 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Descriptive Statistics

Variable	Sum	Mean	Uncorrected SS	Variance	Standard Deviation
Intercept	60.00000	1.00000	60.00000	0	0
calc	34492	574.86267	19828186	2.72222	1.64991
obs	34495	574.92433	19832449	2.87462	1.69547

Correlation

Variable	calc	obs
calc	1.0000	0.9770
obs	0.9770	1.0000

-- aa=2 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	161.89178	161.89178	1217.75	<.0001
Error	58	7.71069	0.13294		
Corrected Total	59	169.60247			

Root MSE	0.36461	R-Square	0.9545
Dependent Mean	574.92433	Adj R-Sq	0.9538
Coeff Var	0.06342		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-2.22630	16.53907	-0.13	0.8934
calc	1	1.00398	0.02877	34.90	<.0001

------------------------------------ aa=2 ------------------------------------

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Dep Var obs	Predicted Value	Std Error Mean Predict	95% CL Mean		95% CL Predict		Residual
1	573.2300	574.0783	0.0529	573.9723	574.1843	573.3408	574.8158	-0.8483
2	573.5200	574.2691	0.0507	574.1676	574.3705	573.5322	575.0059	-0.7491
3	576.0900	576.8292	0.0721	576.6849	576.9735	576.0852	577.5732	-0.7392
4	573.3900	574.0984	0.0527	573.9929	574.2039	573.3610	574.8358	-0.7084
5	576.3400	576.9597	0.0750	576.8097	577.1098	576.2146	577.7048	-0.6197
6	573.7500	574.2389	0.0510	574.1369	574.3410	573.5020	574.9759	-0.4889
7	573.7000	574.1185	0.0524	574.0135	574.2234	573.3811	574.8558	-0.4185
8	572.7200	573.1446	0.0694	573.0057	573.2835	572.4017	573.8876	-0.4246
9	573.7500	574.1185	0.0524	574.0135	574.2234	573.3811	574.8558	-0.3685
10	576.0300	576.3875	0.0630	576.2613	576.5136	575.6468	577.1281	-0.3575
11	573.8000	574.1386	0.0522	574.0341	574.2430	573.4013	574.8758	-0.3386
12	578.9500	579.2588	0.1328	578.9930	579.5247	578.4821	580.0356	-0.3088
13	573.8900	574.1687	0.0518	574.0650	574.2724	573.4315	574.9059	-0.2787
14	573.7900	574.0582	0.0532	573.9517	574.1648	573.3206	574.7958	-0.2682
15	573.0800	573.3454	0.0653	573.2147	573.4761	572.6039	574.0869	-0.2654
16	573.7400	573.9880	0.0542	573.8795	574.0964	573.2501	574.7258	-0.2480
17	577.7900	578.0340	0.1008	577.8323	578.2357	577.2768	578.7912	-0.2440
18	574.1200	574.2891	0.0505	574.1881	574.3902	573.5523	575.0260	-0.1691
19	574.0000	574.1586	0.0519	574.0547	574.2626	573.4214	574.8959	-0.1586
20	572.9200	573.0743	0.0709	572.9324	573.2162	572.3308	573.8179	-0.1543
21	572.9800	573.1346	0.0696	572.9952	573.2739	572.3915	573.8776	-0.1546
22	575.1500	575.2931	0.0482	575.1966	575.3897	574.5569	576.0293	-0.1431
23	573.3900	573.5161	0.0620	573.3920	573.6402	572.7758	574.2564	-0.1261
24	573.3400	573.4358	0.0635	573.3086	573.5629	572.6949	574.1766	-0.0958
25	577.7700	577.8633	0.0965	577.6702	578.0564	577.1083	578.6183	-0.0933
26	579.0900	579.1384	0.1296	578.8789	579.3978	578.3638	579.9130	-0.0484
27	573.8800	573.8675	0.0560	573.7554	573.9795	573.1291	574.6059	0.0125
28	574.6600	574.6506	0.0477	574.5551	574.7461	573.9145	575.3867	0.009419
29	573.8300	573.7771	0.0574	573.6622	573.8920	573.0383	574.5160	0.0529
30	577.4600	577.4015	0.0852	577.2310	577.5720	576.6520	578.1510	0.0585
31	574.2900	574.1888	0.0516	574.0855	574.2920	573.4516	574.9259	0.1012
32	574.1300	573.9980	0.0540	573.8898	574.1062	573.2602	574.7358	0.1320
33	574.3200	574.1888	0.0516	574.0855	574.2920	573.4516	574.9259	0.1312
34	574.2500	574.1185	0.0524	574.0135	574.2234	573.3811	574.8558	0.1315
35	575.6900	575.5642	0.0505	575.4631	575.6653	574.8274	576.3010	0.1258
36	574.3900	574.2590	0.0508	574.1574	574.3607	573.5221	574.9959	0.1310
37	573.4000	573.2550	0.0671	573.1207	573.3894	572.5129	573.9972	0.1450
38	579.1200	578.9777	0.1253	578.7269	579.2286	578.2060	579.7495	0.1423
39	574.5900	574.3895	0.0495	574.2905	574.4886	573.6530	575.1261	0.2005
40	574.1300	573.8976	0.0555	573.7865	574.0087	573.1593	574.6359	0.2324
41	574.5300	574.2791	0.0506	574.1779	574.3803	573.5423	575.0159	0.2509

```
---------------------------------------- aa=2 ----------------------------------------

                                 The REG Procedure
                                  Model: MODEL1
                             Dependent Variable: obs

                                 Output Statistics

     Std Error  Student                   Cook's            Hat Diag     Cov
Obs   Residual Residual    -2-1 0 1 2          D  RStudent         H   Ratio    DFFITS

  1      0.361   -2.352 |  ****|      |    0.060   -2.4509    0.0211  0.8656   -0.3597
  2      0.361   -2.075 |  ****|      |    0.042   -2.1374    0.0193  0.9049   -0.3000
  3      0.357   -2.068 |  ****|      |    0.087   -2.1304    0.0391  0.9244   -0.4296
  4      0.361   -1.963 |   ***|      |    0.041   -2.0146    0.0209  0.9216   -0.2942
  5      0.357   -1.737 |   ***|      |    0.067   -1.7684    0.0423  0.9716   -0.3714
  6      0.361   -1.354 |    **|      |    0.018   -1.3643    0.0196  0.9903   -0.1927
  7      0.361   -1.160 |    **|      |    0.014   -1.1633    0.0207  1.0088   -0.1690
  8      0.358   -1.186 |    **|      |    0.026   -1.1905    0.0362  1.0228   -0.2308
  9      0.361   -1.021 |    **|      |    0.011   -1.0216    0.0207  1.0196   -0.1484
 10      0.359   -0.995 |     *|      |    0.015   -0.9953    0.0299  1.0311   -0.1747
 11      0.361   -0.938 |     *|      |    0.009   -0.9372    0.0205  1.0252   -0.1355
 12      0.340   -0.910 |     *|      |    0.063   -0.9082    0.1327  1.1600   -0.3553
 13      0.361   -0.772 |     *|      |    0.006   -0.7694    0.0202  1.0351   -0.1105
 14      0.361   -0.744 |     *|      |    0.006   -0.7407    0.0213  1.0379   -0.1093
 15      0.359   -0.740 |     *|      |    0.009   -0.7370    0.0321  1.0496   -0.1341
 16      0.361   -0.688 |     *|      |    0.005   -0.6845    0.0221  1.0416   -0.1029
 17      0.350   -0.696 |     *|      |    0.020   -0.6932    0.0764  1.1024   -0.1994
 18      0.361   -0.468 |      |      |    0.002   -0.4652    0.0192  1.0476   -0.0650
 19      0.361   -0.440 |      |      |    0.002   -0.4365    0.0203  1.0498   -0.0628
 20      0.358   -0.432 |      |      |    0.004   -0.4285    0.0378  1.0692   -0.0849
 21      0.358   -0.432 |      |      |    0.004   -0.4288    0.0365  1.0677   -0.0834
 22      0.361   -0.396 |      |      |    0.001   -0.3931    0.0175  1.0482   -0.0525
 23      0.359   -0.351 |      |      |    0.002   -0.3482    0.0289  1.0617   -0.0601
 24      0.359   -0.267 |      |      |    0.001   -0.2646    0.0304  1.0652   -0.0468
 25      0.352   -0.265 |      |      |    0.003   -0.2633    0.0700  1.1107   -0.0722
 26      0.341   -0.142 |      |      |    0.001   -0.1407    0.1264  1.1843   -0.0535
 27      0.360   0.0348 |      |      |    0.000    0.0345    0.0236  1.0603    0.0054
 28      0.361   0.0261 |      |      |    0.000    0.0258    0.0171  1.0534    0.0034
 29      0.360    0.147 |      |      |    0.000    0.1456    0.0248  1.0609    0.0232
 30      0.355    0.165 |      |      |    0.001    0.1637    0.0546  1.0941    0.0393
 31      0.361    0.281 |      |      |    0.001    0.2783    0.0200  1.0537    0.0398
 32      0.361    0.366 |      |      |    0.002    0.3633    0.0220  1.0538    0.0545
 33      0.361    0.364 |      |      |    0.001    0.3609    0.0200  1.0517    0.0516
 34      0.361    0.365 |      |      |    0.001    0.3618    0.0207  1.0524    0.0526
 35      0.361    0.348 |      |      |    0.001    0.3457    0.0192  1.0512    0.0484
 36      0.361    0.363 |      |      |    0.001    0.3600    0.0194  1.0511    0.0506
 37      0.358    0.404 |      |      |    0.003    0.4015    0.0339  1.0657    0.0752
 38      0.342    0.415 |      |      |    0.012    0.4125    0.1182  1.1671    0.1510
 39      0.361    0.555 |      |*     |    0.003    0.5516    0.0184  1.0437    0.0756
 40      0.360    0.645 |      |*     |    0.005    0.6416    0.0232  1.0448    0.0988
 41      0.361    0.695 |      |*     |    0.005    0.6917    0.0192  1.0382    0.0969
```

-- aa=2 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

	-------DFBETAS-------	
Obs	Intercept	calc
1	-0.1656	0.1647
2	-0.1119	0.1112
3	0.3246	-0.3254
4	-0.1329	0.1322
5	0.2884	-0.2891
6	-0.0747	0.0742
7	-0.0749	0.0745
8	-0.1701	0.1696
9	-0.0658	0.0654
10	0.1158	-0.1162
11	-0.0588	0.0585
12	0.3319	-0.3322
13	-0.0464	0.0462
14	-0.0512	0.0510
15	-0.0932	0.0930
16	-0.0512	0.0509
17	0.1760	-0.1763
18	-0.0236	0.0235
19	-0.0267	0.0265
20	-0.0637	0.0635
21	-0.0616	0.0615
22	0.0114	-0.0115
23	-0.0392	0.0391
24	-0.0315	0.0314
25	0.0630	-0.0631
26	0.0498	-0.0499
27	0.0029	-0.0029
28	0.0006	-0.0006
29	0.0133	-0.0133
30	-0.0327	0.0328
31	0.0164	-0.0163
32	0.0269	-0.0267
33	0.0212	-0.0211
34	0.0233	-0.0232
35	-0.0174	0.0176
36	0.0191	-0.0190
37	0.0537	-0.0536
38	-0.1398	0.1399
39	0.0236	-0.0234
40	0.0526	-0.0524
41	0.0357	-0.0354

-- aa=2 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Dep Var obs	Predicted Value	Std Error Mean Predict	95% CL Mean		95% CL Predict		Residual
42	575.6600	575.4136	0.0491	575.3153	575.5119	574.6772	576.1501	0.2464
43	574.2900	574.0281	0.0536	573.9208	574.1354	573.2904	574.7658	0.2619
44	573.9700	573.6968	0.0588	573.5792	573.8144	572.9575	574.4361	0.2732
45	577.4000	577.1304	0.0788	576.9726	577.2882	576.3837	577.8771	0.2696
46	574.9400	574.6305	0.0478	574.5348	574.7262	573.8944	575.3666	0.3095
47	575.7900	575.4839	0.0497	575.3843	575.5834	574.7473	576.2205	0.3061
48	574.3500	574.0181	0.0538	573.9105	574.1257	573.2803	574.7558	0.3319
49	574.1800	573.8273	0.0566	573.7140	573.9406	573.0887	574.5659	0.3527
50	574.1600	573.7872	0.0573	573.6726	573.9018	573.0484	574.5260	0.3728
51	574.7800	574.3494	0.0499	574.2496	574.4492	573.6127	575.0860	0.4306
52	574.6500	574.2088	0.0513	574.1061	574.3116	573.4718	574.9459	0.4412
53	573.9000	573.4558	0.0631	573.3295	573.5822	572.7151	574.1966	0.4442
54	578.4800	578.0240	0.1005	577.8227	578.2252	577.2669	578.7810	0.4560
55	575.1000	574.5803	0.0481	574.4840	574.6766	573.8441	575.3165	0.5197
56	574.6700	574.0884	0.0528	573.9826	574.1941	573.3509	574.8258	0.5816
57	574.7300	574.1486	0.0521	574.0444	574.2528	573.4113	574.8858	0.5814
58	578.4700	577.7228	0.0930	577.5366	577.9089	576.9695	578.4760	0.7472
59	575.3900	575.3734	0.0488	575.2758	575.4711	574.6371	576.1098	0.0166
60	577.5600	577.5420	0.0886	577.3648	577.7193	576.7910	578.2931	0.0180

Output Statistics

Obs	Std Error Residual	Student Residual	-2-1 0 1 2	Cook's D	RStudent	Hat Diag H	Cov Ratio	DFFITS
42	0.361	0.682	| |* |	0.004	0.6788	0.0181	1.0377	0.0923
43	0.361	0.726	| |* |	0.006	0.7232	0.0216	1.0391	0.1075
44	0.360	0.759	| |* |	0.008	0.7564	0.0260	1.0420	0.1235
45	0.356	0.757	| |* |	0.014	0.7545	0.0467	1.0648	0.1670
46	0.361	0.856	| |* |	0.006	0.8542	0.0172	1.0271	0.1130
47	0.361	0.847	| |* |	0.007	0.8454	0.0186	1.0291	0.1164
48	0.361	0.920	| |* |	0.009	0.9192	0.0217	1.0277	0.1370
49	0.360	0.979	| |* |	0.012	0.9788	0.0241	1.0262	0.1538
50	0.360	1.035	| |** |	0.014	1.0361	0.0247	1.0227	0.1647
51	0.361	1.192	| |** |	0.014	1.1966	0.0187	1.0041	0.1652
52	0.361	1.222	| |** |	0.015	1.2275	0.0198	1.0026	0.1746
53	0.359	1.237	| |** |	0.024	1.2426	0.0300	1.0118	0.2185
54	0.350	1.301	| |** |	0.070	1.3092	0.0760	1.0561	0.3755
55	0.361	1.438	| |** |	0.018	1.4516	0.0174	0.9799	0.1931
56	0.361	1.612	| |*** |	0.028	1.6354	0.0210	0.9649	0.2394
57	0.361	1.611	| |*** |	0.027	1.6341	0.0204	0.9645	0.2357

-- aa=2 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Std Error Residual	Student Residual	-2-1 0 1 2	Cook's D	RStudent	Hat Diag H	Cov Ratio	DFFITS
58	0.353	2.119	| |**** |	0.156	2.1876	0.0650	0.9425	0.5770
59	0.361	0.0458	| | |	0.000	0.0454	0.0179	1.0542	0.0061
60	0.354	0.0508	| | |	0.000	0.0503	0.0590	1.1002	0.0126

Output Statistics

Obs	-------DFBETAS------- Intercept	calc
42	-0.0261	0.0263
43	0.0518	-0.0515
44	0.0742	-0.0739
45	-0.1337	0.1340
46	0.0202	-0.0199
47	-0.0372	0.0375
48	0.0665	-0.0662
49	0.0858	-0.0854
50	0.0941	-0.0938
51	0.0550	-0.0546
52	0.0702	-0.0697
53	0.1461	-0.1456
54	-0.3313	0.3318
55	0.0401	-0.0396
56	0.1092	-0.1086
57	0.1013	-0.1007
58	-0.4967	0.4976
59	-0.0016	0.0016
60	-0.0107	0.0107

Sum of Residuals	1.0102E-11
Sum of Squared Residuals	7.71069
Predicted Residual SS (PRESS)	8.22388

-- aa=3 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Descriptive Statistics

Variable	Sum	Mean	Uncorrected SS	Variance	Standard Deviation
Intercept	18.00000	1.00000	18.00000	0	0
calc	10356	575.33056	5958135	2.40445	1.55063
obs	10356	575.35056	5958558	2.87866	1.69666

Correlation

Variable	calc	obs
calc	1.0000	0.9520
obs	0.9520	1.0000

aa=3

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	44.35494	44.35494	154.87	<.0001
Error	16	4.58236	0.28640		
Corrected Total	17	48.93729			

Root MSE	0.53516	R-Square	0.9064
Dependent Mean	575.35056	Adj R-Sq	0.9005
Coeff Var	0.09301		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-23.96542	48.15826	-0.50	0.6255
calc	1	1.04169	0.08371	12.44	<.0001

------------------------------------ aa=3 ------------------------------------

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Dep Var obs	Predicted Value	Std Error Mean Predict	95% CL Mean		95% CL Predict		Residual
1	573.4800	574.5062	0.1432	574.2026	574.8098	573.3318	575.6806	-1.0262
2	576.0300	576.5479	0.1586	576.2116	576.8842	575.3646	577.7312	-0.5179
3	575.5300	575.9854	0.1361	575.6970	576.2738	574.8148	577.1560	-0.4554
4	573.7500	574.0687	0.1629	573.7235	574.4139	572.8828	575.2546	-0.3187
5	573.7000	573.9958	0.1666	573.6426	574.3490	572.8076	575.1840	-0.2958
6	573.8100	574.1104	0.1608	573.7696	574.4512	572.9258	575.2949	-0.3004
7	576.3000	576.5271	0.1576	576.1929	576.8613	575.3444	577.7098	-0.2271
8	573.9600	574.0166	0.1655	573.6657	574.3675	572.8291	575.2041	-0.0566
9	574.0300	574.0270	0.1650	573.6773	574.3768	572.8398	575.2142	0.002969
10	577.2000	577.2979	0.2010	576.8719	577.7240	576.0861	578.5098	-0.0979
11	577.1400	577.1104	0.1895	576.7087	577.5121	575.9069	578.3139	0.0296
12	577.7300	577.7146	0.2280	577.2312	578.1980	576.4814	578.9478	0.0154
13	574.3000	574.1312	0.1597	573.7926	574.4698	572.9473	575.3151	0.1688
14	573.7100	573.4645	0.1972	573.0465	573.8825	572.2555	574.6736	0.2455
15	577.7900	577.5792	0.2190	577.1148	578.0436	576.3533	578.8050	0.2108
16	574.5000	574.0270	0.1650	573.6773	574.3768	572.8398	575.2142	0.4730
17	578.4700	577.5375	0.2163	577.0790	577.9961	576.3139	578.7612	0.9325
18	574.8800	573.6624	0.1852	573.2698	574.0551	572.4619	574.8630	1.2176

Output Statistics

Obs	Std Error Residual	Student Residual	-2-1 0 1 2	Cook's D	RStudent	Hat Diag H	Cov Ratio	DFFITS
1	0.516	-1.990	| ***| |	0.153	-2.2214	0.0716	0.6939	-0.6170
2	0.511	-1.013	| **| |	0.049	-1.0142	0.0879	1.0924	-0.3148
3	0.518	-0.880	| *| |	0.027	-0.8733	0.0646	1.1015	-0.2296
4	0.510	-0.625	| *| |	0.020	-0.6128	0.0926	1.1934	-0.1958
5	0.509	-0.582	| *| |	0.018	-0.5692	0.0969	1.2072	-0.1865
6	0.510	-0.588	| *| |	0.017	-0.5760	0.0902	1.1971	-0.1814
7	0.511	-0.444	| | |	0.009	-0.4326	0.0868	1.2154	-0.1333
8	0.509	-0.111	| | |	0.001	-0.1078	0.0957	1.2562	-0.0350
9	0.509	0.00583	| | |	0.000	0.005647	0.0950	1.2573	0.0018
10	0.496	-0.197	| | |	0.003	-0.1914	0.1411	1.3182	-0.0776
11	0.500	0.0591	| | |	0.000	0.0572	0.1254	1.3003	0.0217
12	0.484	0.0318	| | |	0.000	0.0308	0.1816	1.3900	0.0145
13	0.511	0.330	| | |	0.005	0.3211	0.0891	1.2320	0.1004
14	0.498	0.493	| | |	0.019	0.4814	0.1358	1.2767	0.1908
15	0.488	0.432	| | |	0.019	0.4205	0.1675	1.3351	0.1886
16	0.509	0.929	| |* |	0.045	0.9248	0.0950	1.1253	0.2997
17	0.489	1.905	| |*** |	0.354	2.0976	0.1634	0.8130	0.9270

-- aa=3 --

The REG Procedure
Model: MODEL1
Dependent Variable: obs

Output Statistics

Obs	Std Error Residual	Student Residual	-2-1 0 1 2	Cook's D	RStudent	Hat Diag H	Cov Ratio	DFFITS
18	0.502	2.425	| |**** |	0.400	2.9525	0.1198	0.5171	1.0893

Output Statistics

	-------DFBETAS-------	
Obs	Intercept	calc
1	-0.2937	0.2923
2	0.1903	-0.1909
3	0.0855	-0.0861
4	-0.1242	0.1238
5	-0.1222	0.1218
6	-0.1128	0.1125
7	0.0797	-0.0800
8	-0.0228	0.0227
9	0.0012	-0.0012
10	0.0603	-0.0604
11	-0.0161	0.0162
12	-0.0121	0.0121
13	0.0618	-0.0616
14	0.1470	-0.1467
15	-0.1539	0.1542
16	0.1938	-0.1932
17	-0.7517	0.7531
18	0.7996	-0.7977

Sum of Residuals	0
Sum of Squared Residuals	4.58236
Predicted Residual SS (PRESS)	5.80931

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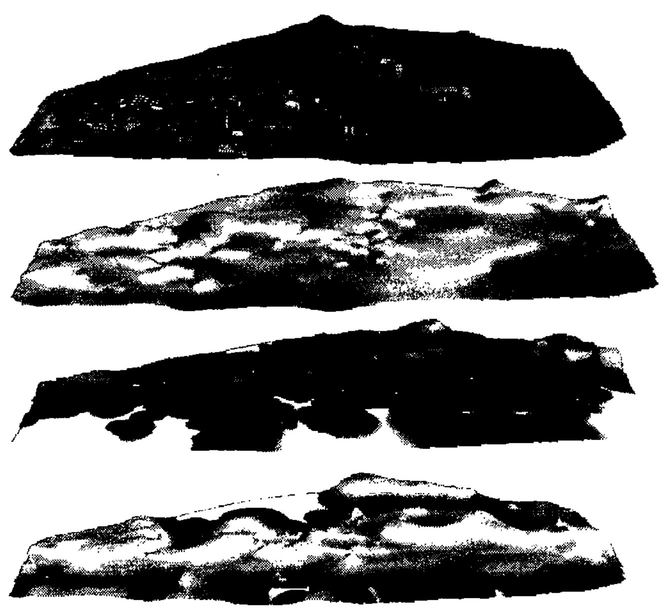
BASF WYANDOTTE NORTH WORKS

Corrective Measures Study
Groundwater Modeling

CONCEPTUAL HYDROGEOLOGIC MODEL
&
MODEL CALIBRATION REPORT



June 2002

Report by:

waterloo hydrogeologic

SOFTWARE · CONSULTING · TRAINING

Report for:

BASF

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1.0 Introduction

The section presents an overview of the relevant history of the BASF North Works Facility (the site), including a description of the environmental conditions at the site and prior site characterization and remediation work. This report is prepared by Waterloo Hydrogeologic, Inc. (WHI) for BASF Corporation.

1.1 Overview

The 231 acre site on the western shore of the Detroit River was developed in the 1890s and has supported a diverse industrial operation throughout its history. Most of the original low-lying terrain on the site is now covered with a variety of fill materials consisting principally of by-products of the historic on-site industrial activities. Some of these fill materials are now considered potentially hazardous to human health and the environment.

A groundwater study was undertaken in 1984 by S.S. Papadopulos & Associates, Inc. (SSPA), and a control plan was then submitted to the State of Michigan. This control plan formed the basis for a 1986 Consent Decree which is still in force. The Decree specifies remedial measures which may be summarized as:

1. operation of a groundwater extraction and treatment system for at least 30 years
2. demonstration that an inward hydraulic gradient toward each extraction well exists, preventing the flow of contaminated groundwater to the Detroit River
3. water level monitoring.

In 1994, BASF entered into an Administrative Order on Consent with USEPA, which is concurrently in force. The objectives include:

1. to continue to take measures to prevent the flow of contaminated groundwater from the Facility to the Detroit River and the Wayne County Department of Public Works sewerage system (except as provided by permit)
2. to complete an RCRA Facility Investigation (RFI)
3. to complete a Corrective Measures Study (CMS)
4. if necessary, to complete a Corrective Measures Implementation (CMI).

The EPA Order specifies that the CMS will "identify and evaluate alternatives for the corrective action necessary to prevent or mitigate any migration or releases of hazardous wastes or hazardous constituents at or from the Facility." The current groundwater modeling serves to assist in the preparation of supporting documentation for the CMS.

1.2 Current Conditions

The BASF Corporation North Works facility is located on the U.S. shore of the Detroit River at 1609 Biddle Avenue, Wyandotte, Michigan. It is part of Sections 21 and 28, T. 3 S., R. 11 E. It is approximately 1 mile north of downtown Wyandotte.

The site occupies approximately 231 acres. It is generally described as bounded on the north by Perry Place, on the south by Mulberry Street, on the east by the U.S. Harbor Line of the Detroit River, (Trenton

Channel) and on the west by Biddle Avenue (**Figure 1. Site Location** – please note that all full-page figures are located in **Appendix A** following the text of this report).

The North Works location was part of a Detroit River marsh. Development as a manufacturing facility began with drainage and placement of fill materials. Marshland originally covered most of the eastern part of the property (ca. 1876).

Between 1890 and 1928, the North Works was developed through improved drainage and addition of fill. Today, approximately 25 to 30 percent of the surface area is covered with buildings, paved streets, paved parking lots, tank farms, surface impoundments and docks. Although several different manufacturing plants continue to operate at this site, the former Soda Ash Plant and structures associated with soda ash production and storage have been removed. Also, brine wells, a coke plant, an electric power generating plant and other related structures have been discontinued and removed. Many of the above ground structures have been demolished, but the concrete at or below grade remains. An extensive network of utilities including potable and service water lines, storm sewers, sanitary sewers, and other utilities typical of an industrial facility this size and age remain underground even though large sections are no longer used and are isolated from the active lines (SSPA, 1984). Drainage ditches have also been filled.

The existing site layout, including definition of Areas of Concern (AOCs) and Solid Waste Management Units (SWMUs), is shown in **Figure 2. Existing Site Layout**. This figure alsc shows the locations of the existing groundwater extraction wells, which have been in operation since 1986. For additional details of the site's history and current conditions, refer to the Current Conditions Report (Woodward-Clyde Consultants, 1994; updated by Parsons Engineering Science, Inc., 1998).

1.3 Prior Work

The conceptual model of the site is based on the findings of the following reports:

1. Rate and Direction of Ground-Water Flow at the North Works, BASF Wyandotte Corporation, Wyandotte, Michigan, Volume 1: Main Report, and Volume II: Appendices
   S.S. Papadopulos & Associates, Inc.
   December 1984
2. RCRA Facility Investigation Report of Current Conditions
   Woodward-Clyde Consultants. June 1994.
   Updated by Parsons Engineering Science, Inc. October 1998.
3. Phase I RCRA Facility Investigation Report for BASF-Wyandotte Facility
   QST Environmental (formerly Environmental Science & Engineering, Inc.)
   26 February 1999
4. RCRA Corrective Measures Study, Field Program Report, for the BASF North Works Facility, Wyandotte, Michigan, USEPA ID Number MID 064197742
   Parsons Engineering Science, Inc.
   March 2000

There have been many additional soils investigations at the site, and where information from those investigations has been used, they are referenced directly in the text of the present report.

1.4 Report Organization

This report follows the Criteria for Groundwater Modeling Reports of the State of Michigan Department of Environmental Quality (MDEQ). It is divided into nine sections.

Section 1, **Introduction**, presents an overview of the site's relevant history, including a description of the problems at the site and prior characterization and remediation work.

Section 2, **Model Objectives**, explains the purposes of using a groundwater model (i.e. understanding of hydrogeological processes at the site, estimation of flow direction and flow rates, identification of possible receptors, capture zone of wells, evaluation of remediation scenarios).

Section 3, **Hydrogeologic Characterization**, describes the factors necessary to understand the importance of relevant flow or solute transport processes at the site, including regional geologic data, topographic data, surface hydrologic data, geologic cross-sections from soil borings and well logs, well construction diagrams and soil boring logs, measured water level data, estimates of hydraulic conductivity derived from pumping test and slug test data, and estimated flow rates of groundwater sources and sinks.

Section 4, **Model Conceptualization**, assembles data describing field conditions in a systematic way to describe groundwater flow and contaminant transport processes at the site.

Section 5, **Numerical Modeling Approach**, discusses details of the conceptual model and its implementation in MODFLOW.

Section 6, **Model Implementation**, describes how the conceptual hydrogeologic model of the site was translated into a numerical hydrogeologic model, with details on model layers, areal grid, boundary conditions, recharge, hydraulic conductivity, storage, and effective porosity.

Section 7, **Model Calibration**, presents the evidence to demonstrate model fidelity, that is, the ability of the model to reproduce observed field conditions. Topic covered include predicted water levels and flow directions, calibration statistics, water balance, as well as parameter optimization and sensitivity analysis.

Section 8, **Summary,** reviews the key findings and recommendations arising from the development of the hydrogeologic model of the BASF Wyandotte North Works site, just prior to predictive simulations.

Section 9, **Bibliography**, references other studies cited in the present report.

Appendices A through D contain full-page figures, supporting calculations and other reference material, including a glossary and list of abbreviations.

1.5 Quality Assurance

This report has been reviewed internally by Dr. Robert W. Cleary of WHI and other members of the project team, including Parsons Engineering Science and BASF. All work has been conducted in conformance with the following guidelines:

ASTM D 5609-94 $^{\varepsilon 1}$	*Standard Guide for Defining Boundary Conditions in Ground-Water Flow Modeling*
ASTM E 1689-95	*Standard Guide for Developing Conceptual Site Models for Contaminated Sites*

ASTM D 5610-94 ε1	*Standard Guide for Defining Initial Conditions in Ground-Water Flow Modeling*
ASTM D 5718-95 ε1	*Standard Guide for Documenting a Ground-Water Flow Model Application.*

This report follows the structure and content guidelines of the MDEQ for Groundwater Modeling Reports (ref. http://www.michigan.gov/deq/1,1607,7-135-3313_3679_3708-15204--,00.html#Introduction , Revised March 07, 2001).

2.0 Model Objectives

The model objectives define the purpose of using a groundwater model.

The purposes of the current groundwater modeling project include:

- improved understanding of hydrogeological processes at the site
- estimation of groundwater flow directions and groundwater flow rates at the site
- evaluation of possible flows of groundwater from the site to off-site receptors
- simulation of alternative corrective (remedial) measures.

The developed model will be useful in evaluating the performance of the remediation system, designing additional components /monitors for the remediation system (as needed), and assessing future impacts of contaminant plumes at potential receptors. Predictions using the calibrated model will be based on scenarios developed by BASF and Parsons Engineering Science. The final groundwater modeling report will be incorporated into the CMS Report.

3.0 Hydrogeologic Characterization

MDEQ recommends that the following hydrogeological and geochemical information be considered for appropriate characterization:

- Regional geologic data depicting subsurface geology
- Topographic data (including surface-water elevations)
- Presence of surface-water bodies and measured stream-discharge (base flow) data (if available)
- Geologic cross-sections drawn from soil borings and well logs
- Well construction diagrams and soil boring logs
- Measured hydraulic-head data
- Estimates of hydraulic conductivity derived from aquifer and/or slug test data
- Location and estimated flow rate of groundwater sources and sinks.

3.1 Regional Geology

As shown in **Figure 3. Surrounding Subsurface Information,** there are no water wells within a 1 mile radius of the site. This was confirmed by Danyle Ordway of MDEQ on 04 Sept 2001.

At a regional scale, surficial deposits are variable and not continuous. Sands with intermittent finer sediments underlie the surficial deposits. These are likely fluvial deposits associated with the Detroit River. Glacial lacustrine clay underlies the sands. This lacustrine clay is described as:

gray to dark reddish brown, varved in some localities, chiefly underlies extensive, flat, low-lying areas formerly inundated by glacial Great Lakes, but also occurs in separate, small lake basins, includes small areas of lacustrine sand and clay-rich till. Thickness: 1 – 10 m. (Michigan DNR, 1982)

The clay was deposited during the latest interglacial stage when lake levels were higher than they are today. This clay has low permeability and effectively segregates upper groundwater in the surficial deposits from water-bearing zones below.

At a depth of approximately 70 ft, there is a thick bed of dolomite (Dundee or Detroit River Group). The water present in the dolomite has a high sulfur content rendering it unfit for consumption. Below the dolomite, there is thick layer of sandstone (Sylvania) and then various interbedded layers of limestone, sandstone, gypsum and salt to depths of 1500 ft (see **Figure 4. Regional Geology**).

The isolation of the shallow aquifer system from any aquifer system below the lacustrine clay effectively eliminates vertical migration, except for the potential at wells, which penetrate between layers. Upward gradients further prevent contamination, as the Detroit River is a regional discharge zone.

SSPA (1984) state that:

> "The low permeability of the lake clay and small differences in the ground-water levels between the dolomite and the surficial materials (Tom Piper, Staff Geologist, BASF Wyandotte Corporation, personal communication, 1984) suggest that flow through the lake clay is very small." (page 2)

3.2 Site Hydrostratigraphy

Stratigraphy refers to the study of characteristics and attributes of geologic materials (rock, soils, fill) *as layers* (also referred to as strata, beds, or units), visually separable from the layers above and below; and their interpretation in terms of mode of origin and geologic history. Hydrostratigraphy refers specifically to stratigraphy from a hydrogeologic perspective, i.e. emphasizing those characteristics of geologic layers that affect the flow, transport, and evolution of groundwater and dissolved constituents.

pick up?

3.2.1 Sources of Information

The hydrostratigraphic characterization of the site is based on a series of geotechnical and geoenvironmental investigations at the site over the past 30 years. In general, these investigations are of good quality, and there is excellent correlation of the hydrostratigraphy at the site between different investigators. Some care is required in interpreting the results of these previous investigations, since their objectives differ from those of the present report. **Table 1** presents a chronological listing of these investigations, along with the names of the soil borings as they appear in **Figure 5. Environmental and Geotechnical Borehole Locations.**

Table 1. Sources of Information for Hydrostratigraphy

Author	Title	Focus	Date
1. City of Wyandotte	Wyandotte Sewer Drawings #22, #23, #24	municipal	December 1965
2. unknown	Log of Soil Boring, SE Corner Hudson Street Lot 120 & 126	geotech.	no date
3. Michigan Drilling Co	Soils Exploration Proposed Building Main Research Building	geotech.	16 Jul 1960
4. Dames & Moore	Report of Soils Investigation, Proposed Liquid Calcium Chloride Storage Pond	geotech.	27 Nov 1963
5. Michigan Drilling Co	Soils Exploration Proposed Plant	geotech.	06 Nov 1963
6. Michigan Drilling Co	Proposed Pilot Plant Laboratory	geotech.	09 Jun 1964
7. Michigan Drilling Co	Soils Exploration Proposed Plant Expansion	geotech.	29 Jul 1968
8. Raymond International Inc	Boring Report, Primary Waste Treatment Facilities, Wyandotte Polyol Plant	geotech.	13 Apr 1973
9. Soils and Foundations Assoc.	Report of Subsurface Conditions at the Proposed Polyol Retention Pond	geotech.	23 Jan 1974
10. Soils & Materials Engineers Inc	Subsurface Investigation Liquid Nitrogen Storage Tank Foundation	geotech.	22 Dec 1977
11. McDowell & Assoc.	Soils Investigation, Proposed Boiler Installation, Building 58k	geotech.	13 Feb 1981
12. McDowell & Assoc.	Soils Investigation Proposed Oil Storage Tank 150,000 Gallon Capacity	geotech.	08 Sep 1981
13. Michigan Testing Engineers Inc	Proposed Sump Installation	geotech.	01 Dec 1981
14. McDowell & Assoc.	Soils Investigation Truck & Railroad Scales	geotech.	31 May 1984
15. McDowell & Assoc.	Soils Investigation East of the Vitamin Administration Building	geotech.	25 Jul 1984
16. Testing Engineers & Consultants Inc	Soils Investigation for Elastocell Plant	geotech.	31 Jul 1985
17. Testing Engineers & Consultants Inc	Soils Investigation for Above Ground Tanks	geotech.	13 Nov 1985
18. Professional Services Industries Inc	Soils Exploration and Foundation Recommendations for the Proposed EPP Project	geotech.	27 May 1987
19. Testing Engineers & Consultants Inc	Soils Investigation for Warehouse and Bulk Loading Facility	geotech.	20 Jul 1989
20. McDowell & Assoc	Soils Investigation Proposed Tank and Platform	geotech.	29 Jul 1989
21. Testing Engineers & Consultants Inc	Soils Investigation for TPU Facility	geotech.	23 Jan 1990
22. McDowell & Assoc.	Soils Investigation Proposed Warehouse Building	geotech.	15 Oct 1990
23. ERM Inc	Hydrogeology, Hydrology and Water Quality at the Central Ave Site, Wyandotte Michigan	environ.	20 Mar 1981
24. S.S. Papadopulos & Assoc.	Rate and Direction of Groundwater Flow at the North Works, BASF Wyandotte, Vol 1 Main Report And Vol II Appendices	environ.	December 1984
25. B. Barkel	PDC Investigation	environ.	January 1985
26. S.S. Papadopulos & Assoc.	Installation of Extraction and Monitoring Wells and Piezometers at BASF Corporation Chemicals Division, North & South Works	environ.	December 1986
27. Fluor Daniel GTI	Toluene Remediation Investigation	environ.	May 1992
28. McDowell & Assoc.	Soils Exploration BASF Site, Biddle Avenue and Perry Place	environ.	12 Oct 1995
29. McDowell & Assoc.	Environmental Drilling and PID Results, 4-6 Foot Borings New Railroad Expansion Area	environ.	12 Jul 1996
30. Jack Lanigan Corporation	Replacement Wells & Borings	environ.	1998
31. QST Environmental	Phase I RCRA Facility Investigation Report for BASF-Wyandotte Facility	environ.	26 Feb 1999
32. Parsons Engineering Science	Logs of Corrective Measures Study (CMS) Borings	environ.	August 1999
33. WHI	Logs of Field Investigation Boreholes	environ.	May 2002

3.2.2 General Description of Site Hydrostratigraphy

The conceptual hydrogeologic model is founded on the understanding that the site was developed on marshlands associated with a former meander of the Detroit River, which is incised into the underlying extensive glacial lacustrine clay.

QST (1999) describe five stratigraphic units beneath the site. These five units were classified in descending order as the 1) **Fill** unit, 2) Clay and **Peat** unit, 3) Native **Sand** unit, 4) Lacustrine **Clay** unit, and 5) **Bedrock** unit. These same layers are included in the Conceptual Hydrogeologic Model for the site described in the present report. Note that the **Bedrock** was not included in the ***numerical*** model, though it is part of the conceptual model of the groundwater flow system at the site.

The surface strata are comprised of industrial fill (up to 25 ft in thickness). Fill materials (primarily industrial residues generated on-site) were deposited on-site to fill in marshland areas and raise the entire site to its present grade. This fill varied in nature from alkaline lime waste, including distiller blow-off (DBO), to acidic fly ash and cinders. The fill also includes some deposits of relatively clean sand and clay, metal, wood, and masonry debris. In most instances, the transition from marshland to fill is sharply defined due to borehole evidence of the original vegetation from the marshland bottoms.

In general, the fill rests on peat or organic clays that evolved from the original marsh bottom deposits. Where present, the peat material occurs approximately 5 to 10 ft below land surface (bls) and ranges up to 13 ft in thickness depending on location, though 2 to 3 ft is typical.

The layers below the peat (or below the fill where the peat is absent) consist of sands with discontinuous pockets of clay. Sand is prevalent beneath the western portion of the site, but pinches out to clay to the east in parts of the site. The glacial lacustrine clay described under Section 3.1 (Regional Geology) underlies this sand.

3.2.3 Lacustrine Clay

Soil boring results verified the presence of the Lacustrine Clay unit beneath the site. This unit was generally encountered between 20 to 30 ft bls. Based on interpretations of both site-specific boring results and regional geological information, the Lacustrine Clay unit is expected to be continuous beneath the site and immediate surrounding area. As such, it serves as an effective lower confining layer beneath the site. The lacustrine clay is generally blue-gray, though sometimes brown, and contains some sand and gravel. The presence of some coarser grained material is not expected to affect its hydrogeologic properties significantly.

Based on interpretations of soil boring logs from the site, it appears that the surface of the Lacustrine Clay unit generally dips toward the east. The unit also exhibits a distinct north-south oriented low that is apparent beneath the central portion of the site. Further to the east, the rate of dip along this surface increases dramatically in the area of monitoring wells RFIMW-9 and RFIMW-11 adjacent to the Detroit River (see **Figure 5**). Elevation contours for the top surface of the Lacustrine Clay unit are displayed in **Figure 6. Lacustrine Clay Surface Elevation. Figure 6a** presents the current interpretation of this surface while **Figure 6b** presents the previous interpretation (QST, 1999). The current interpretation incorporates additional data points. The clay ridge delineated in **Figure 6b**, has been included in **Figure 6a** for reference.

3.2.4 Native Sand

Soil boring results identified the presence, or in places the absence, of a fine-grained, well-sorted, silty sand (Native Sand unit) above the Lacustrine Clay unit. Unit thickness varies throughout the site, but typically ranges from 4 to 12 ft, up to a maximum of 23 ft. The average thickness is approximately 6.1 ft, and this layer is generally saturated. Thickness variations across the site are portrayed as an isopach map in **Figure 7. Layer Isopachs.**

The isopach (thickness) plots for the Native Sand unit, as well as the Peat & Clay unit and the Fill unit, were prepared using a natural neighbor interpolation algorithm (20 ft cell size, 10 ft aggregation radius, linear surface solution), which calculates the value of a grid node using the average value of the points surrounding it. The calculation is area-weighted to account for the relative influence of the surrounding points.

The Native Sand unit is generally thickest to the southeast and through the center portion of the site, demonstrating the same north-south linearity that is present on the surface of the underlying clay. Increasing thickness of this unit generally corresponds with lows on the underlying clay surface. Where the elevation of the clay surface rises sufficiently, the unit thins or pinches out.

The Native Sand unit appears to be a channel fill deposit of the pre-historic Detroit River. This sand unit is relatively uniform in grain size and sorting, reflecting the load capacity of the moving water from which it was deposited. Clay interbeds or "stringers" are noted in some of the boring logs at the site. These appear neither extensive nor continuous, though this is uncertain given the variability in the boring logs. Shell remnants are also noted in some logs.

3.2.5 Peat & Clay

The next recognized sequence at the site is a silty, organic-rich clay and interbedded peat sequence (Clay and Peat unit). unit thickness generally ranges from 0 to 4 ft. across the site, although in selected locations it attains a thickness of up to 13 ft. The average thickness is approximately 3.3 ft, where present, and this layer is generally saturated. Soil boring data indicate that the thickness of the unit increases along the southeastern boundary of the site. This trend corresponds with the occurrence of a thicker underlying sand layer and a pronounced low in the surface of the Lacustrine Clay unit. However, other areas of increased thickness are not apparently related to the characteristics of the underlying sand unit. Furthermore, the Clay and Peat unit is absent in some areas of the site, in particular along the western boundary (Biddle Avenue). Although the thickness of the Clay and Peat unit is variable, the material properties of the unit appear to remain relatively constant. In some borehole locations, an inorganic silt or marl occupies this location in the stratigraphic sequence. The Peat & Clay unit is often described as swamp bottom or river bottom deposits in the borehole logs. **Figure 7. Layer Isopachs,** displays an isopach map of this unit. Where the Peat & Clay unit is absent, unconfined conditions are expected.

3.2.6 Fill

Soil boring data indicate that a heterogeneous Fill unit overlies the native materials at the site. Fill material generally consists of a mixture of bi-products from past manufacturing operations, rubble from past site demolition activities, and natural native materials. Categories specifically encountered include:

1. clinker gravel with coal, coke, tar, gravel and sand
2. distiller blow-off (DBO), a fine-grained waste byproduct of the Solvay Process for crude sodium bicarbonate production, consisting of a mixture of sodium carbonate, calcium chloride, sodium chloride, calcium sulfate, sodium sulfate, and some excess lime. DBO is a white, putty-like or paste-like substance with low permeability.
3. gravelly, mottled clay; and
4. construction debris including large blocks of concrete, brick, and pipe.

Fill thickness varies throughout the site, but typically ranges from 6 to 15 ft, up to 25 ft. The average thickness is approximately 9.5 ft, and average saturated thickness is 6.2 ft. Fill thickness variations across the site are displayed in **Figure 7. Layer Isopachs.**

A thick deposit of fill was identified in the eastern portion of the site to the north of Alkali St. (see **Figure 2**). This localized deposit generally coincides with a topographic high area of the site. The fill in this area appears to consist primarily of DBO.

In the southern part of the site in the vicinity of AOC 6 (see **Figure 2**), soil punch data indicates that the fill material primarily consists of clinker gravel, coal, or coke mixed with sand and mottled clay. Laterally isolated DBO deposits were also encountered in this area. North of the extensive DBO deposits, gravelly fill material predominates. Isolated DBO deposits were encountered in the northern portion of the site as well. While these broad classifications are useful, it must be recognized that the fill is the most heterogeneous of the strata identified.

Though not recorded in the borehole logs, there are records of an extensive network of subsurface utility trenches at the site. Where present, these trenches may serve as preferential pathways in the upper few feet of the saturated zone.

pick up here 9/

3.2.7 Hydrogeologic Cross-Sections

Hydrogeologic interpretation refers to a systematic evaluation of borehole data to order and understand the hydrostratigraphic data for the site, including the appropriate exercise of professional judgment. QST (1999) provide the following geologic interpretations of the four geologic cross sections whose locations are shown in **Figure 8. Hydrostratigraphic Cross-Section Locations.** These cross sections are included as **Figure 9** through **Figure 12**. These cross-sections also include the approximate location of the steel seawall (where present, see Section 3.4.3) and the approximate range of water elevation in the river.

These interpreted cross sections are described below, along with updated interpretations based on the Conceptual Hydrogeologic Model work prepared to date. One key difference in methodology between the RFI report and the present report is that the present work is based on an evaluation of all borehole data at the site, including the recent CMS borings (PES, 1999), whereas QST relied primarily on the environmental investigations listed in **Table 1**, in particular references 24, 30, and 31.

Based on the elevation surfaces noted for the Lacustrine Clay Unit, a north-south trending channel that parallels the current river channel is apparently incised into the clay. This fluvial channel creates a localized ridge on the Lacustrine Clay Unit surface parallel to the river in the southern portion of the site, and a corresponding thinning in the Native Sand Unit, as shown in **Figure 12**. In some instances, the Native Sand Unit pinches out at the clay high altogether and under the DBO fill area, as shown on **Figure 7**. This condition acts as an impediment to easterly flow.

Present over a significant portion of the site, the Clay and Peat unit enhances the controlling capabilities of the groundwater extraction system. The low vertical permeability of this Clay and Peat Unit provides a degree of vertical hydraulic separation between the Native Sand and the overlying Fill Unit, as verified in pumping tests by PES (2000).

The presence of the seawall along the eastern boundary of the site is highlighted in **Figure 8**, **Figure 10**, and **Figure 11**. This hydraulic barrier is discussed further in Section 3.4.3 below.

3.3 Topographic Data

Topographic relief of the site is relatively low. The southern half of the site (south of Alkali Street) is flat, and lies between 575 and 580 feet above mean sea level (ft amsl). The northern half of the site (north of Alkali Street) lies between 580 and 585 ft amsl, except in the eastern portion north of Alkali, where DBO residue from soda ash manufacture was deposited and elevations range from 582 to 591 ft amsl. Ground surface contours are plotted in **Figure 13. Elevation of Ground Surface**.

3.4 Surface Water Features

Surface water and groundwater flow is naturally east toward the Detroit River. Groundwater is influenced by surface water drainage, river stage, glacial landforms, the site hydrostratigraphy, the seawall, and the 15 extraction wells located within North Works. There are no streams or creeks which cross the site or receive direct discharge from the site. The two storage ponds (Polyols Pond and Fire-Water Pond) are lined with impervious materials. The Detroit River does not receive significant runoff through sources other than permitted outfalls because the site has been graded to facilitate interior drainage into the outfall system. The surface water collection system is more efficient on the north half of the site than on the undeveloped south half. Minor amounts of surface water flow to the city sewer system. Details of surface water features are presented in the following sub-sections.

3.4.1 Detroit River

The Detroit River connects Lake St. Clair to the north with Lake Erie to the south. Flow in the river is complex due to numerous islands and channels particularly in the southern half of its length, and to effects from fluctuating water levels in Lake Erie. The river is approximately 2,500 to 5,000 ft wide, and drops 3 ft over its 31.7 mile length. The average slope in the Lower Detroit River is approximately 0.027 ft / 1000 ft. The depths in the main channels range from 30 to 50 ft. Retention time averages 21 hours, and the average flow rate is 185,000 ft^3/s. Detroit River average main channel velocities are 1.6 to 3.0 ft/s, but near-surface velocities may be nearly twice that rate in the main channels.

The River is characterized by swift, smooth flow in its mid-portion, with sand deposits occurring in varying thickness along both shores where currents are slower. Fine-grained sediment thickness over bedrock reaches a maximum of 100 feet near Belle Island, which is several miles upstream of the site, but decreases steadily southward to nearly zero in the vicinity of the site. There is no major depositional zone along the Michigan mainland shore from three-fourths of a mile upstream of BASF to approximately three miles downstream

(Ostaszewski, 1997). There is no site-specific data on the deposition of sediments immediately adjacent to the sheet-piling seawall.

3.4.2 Trenton Channel

The site lies directly on the Trenton Channel harbor line, which is maintained by the Corps of Engineers (COE) to a depth of approximately 26 ft. The Trenton Channel represents the section of the Detroit River that flows between Grosse Île and the Michigan mainland. It is approximately 9 miles in length and 750 to 3800 ft wide. The average volumetric flow in the Channel is approximately 45,900 ft^3/s, which is about 25% of the river's total flow. Portions are dredged to maintain a depth of 23 to 30 feet for shipping passage. The COE reports that, due to the lack of accumulated sediment, the portion of the Channel adjacent to the site requires dredging less than once per 10 years.

The bottom sediments can be subjected to regular scouring from the propeller wash of passing freighters. Sand is transported in the main channels when the velocity exceeds 1.4 ft/s, while along the shore and in shallow water areas, where velocities may drop to 0.8 ft/s or less, sand deposition occurs. Navigation channel bottoms are scoured by currents and few sediments are left.

3.4.3 Seawalls

The site has a long seawall that separates the fill from the river. There are two forms of construction used. The original oak seawall measures approximately 4700 ft in length and runs from the northeast corner of the site to a point approximately 850 ft from the southeast corner of the site. It is constructed of double layer of 3 inch thick, overlapping oak timbers. The remaining 850 ft of shoreline to the south is treated with rip-rap stones. A second seawall, consisting of steel sheet pilings approximately 40 ft deep, runs parallel to the first wall for a distance of approximately 3360 ft from the northeast corner of the site. The steel seawall is keyed into the underlying Lacustrine Clay, and is separated from the original seawall by approximately 2 ft. The joints between steel pilings are not sealed. The seawall has three zones, in terms of resistance to horizontal flow, as shown in **Table 2. Seawall Zones**.

Table 2. Seawall Zones

Construction	Length	Resistance to Horizontal Flow
oak timbers and steel pilings	3360 ft	medium to high
oak timbers only	1340 ft	low
rip-rap	850 ft	none

3

3.4.4 On-site Surface Water

There are two on-site ponds, one in the north end (Polyols pond) and one in the south end (Fire-Water Pond). There was also a ditch, described as the Emergency Containment Pond, in the central portion of the site. The Polyol pond and the ditching are also designated as Solid Waste Management Units (SWMU) under the EPA RCRA process. **Figure 2. Existing Site Layout**, shows the location of these ponds.

The Polyols Pond (SWMU E) is a man-made retention pond covering an approximate 160 ft by 60 ft area, located in the northeast corner of the site. It is constructed of earthen dikes lined with clay and contains a concrete wall that divides the pond into two sections.

The Polyols Pond serves as a wastewater retention pond for various sources. Wastewater is neutralized and combined with additional non-contact cooling water/stormwater runoff and discharged through a diffuser pipe to the Detroit River via Outfall 001.

The 6 million gallon Fire-Water Pond formerly received waste water. It is a rubber lined settling pond previously used for calcium chloride liquor storage. This pond was cleaned of precipitate in 1990, relined and converted to its present use for fire protection water storage. The precipitated sludge was removed from the North Works as non-hazardous waste.

The Emergency Containment Pond (SWMU H) is located in the east central portion of the site. The area is located to the south of the Pilot Plant and Vitamins Complexes, north of the Engineered Plastics Complex, and east of the railroad tracks (see **Figure 2**). This SWMU was historically utilized as a retention pond and drainage system that discharged to an outfall on the Detroit River (currently identified as Outfall 003). SWMU H includes approximately 1,600 linear feet of trenching.

The origin of the drainage system dates back to the late 1800s when it was used in dewatering/filling activities for the original Detroit River marshland. Since fragmental records from the 1920s indicate that the site utilized only one drainage network, the system likely was utilized as a combined drainage system. SWMU H gradually evolved up to the 1980s, at which time its primary effluents consisted of stormwater, non-contact cooling water, contact wastewater from the Pilot Plant, and subsequent contact wastewater from the Chemical Engineering Building. None of the drainage system was lined, and it was periodically dredged to maintain flow.

Beginning in the early 1980s, this drainage system was gradually filled in and replaced with a steel piping system with welded joints to prevent infiltration of groundwater to the discharge at Outfall 003. SWMU H is currently used only as the subsurface corridor for the hard-piped drainage system. The overlying areas are maintained as open field areas containing weeds and grassy vegetation.

3.4.5 Surface Water Discharge

Surface water leaves the North Works site through several pathways. These pathways include regulated Outfalls 001, 002 and 003, the Wayne County sewer system, and surface water flow.

BASF has graded the site to enhance drainage on the facility and reduce run off. In general, run off is well controlled on the north half of the site but some run off may occur on the undeveloped south half of the site. There is no discernible floodplain at the site.

3.5 Groundwater – Surface Water Interaction

At a regional scale, the estimated total discharge of groundwater from the Michigan side of the Detroit River from Belle Isle to Point Mouillée is reported to be approximately 50 to 100 ft^3/s (ESEI, 1995). Rates of groundwater seepage are highest in the northern portion of the Detroit River near Belle Isle, and generally decrease downstream, increasing again below the Ecorse River mouth. Groundwater and surface water systems are highly interconnected in the Trenton Channel and the lower Detroit River, due to thin or absent sediments overlying bedrock (MDNR & OME, 1991).

3.6 Groundwater Discharge

Groundwater discharge from the North Works facility is expected to be small because of the combined effects of the natural hydraulic isolation of the site, the groundwater extraction system, and the oak and steel retaining walls erected along the Detroit River bank.

SSPA (1984) note that small quantities of water may leave the site by diffuse flow to the Detroit River along the portion of the waterfront that does not have a steel retaining wall and by flow patterns across the north boundary near Perry Place. PES (2000) confirm the tendency for groundwater to exit the site along the north property edge in the CMS field investigation. QST (1999) evaluated the efficiency of the groundwater extraction system, and concluded that:

> [T]he extraction system appears to be most effective in the southern half of the Facility where a majority of the horizontal hydraulic gradients are essentially flat or slightly toward the interior of the Facility. In contrast, horizontal gradients toward the river along the northern portion of the Facility indicate reasonable potential for off-site migration in these areas. The presence of a groundwater "divide" is indicated roughly parallel to the river along the eastern side of the Facility. Although its location cannot be precisely defined at this time, this divide further supports the conclusion that a component of groundwater flow is likely discharging to the river. (QST, 1999)

The evaluation of the potential for discharge of groundwater from the site is one of the main objectives of the present groundwater modeling work.

3.7 Water Level Data

There are a total of 400 borehole logs in the database for the site. Of these, approximately 150 had operational monitoring wells suitable for water level monitoring as of February 2002. In the past, water levels at the site were referenced to different vertical datums, making it difficult to compare on-site and off-site water levels, or to incorporate historical data in the analysis. During the preparation of the present study, all elevation data for the project were converted to the International Great Lakes Datum of 1985 (IGLD, 1985) to facilitate model implementation and interpretation.

3.7.1 Groundwater Elevations

Many surveys of groundwater levels at the site have been carried out in the past. In most surveys, water levels were measured in only a few wells, failing to provide adequate coverage of the entire site. There are four sets of essentially complete water level data for the site that were used in the preparation of the present report. These are:

1. July 1998: 99 water level measurements taken 27-28 July 1998
2. October 1998: 100 water level measurements taken 13 October 1998
3. December 1999: 120 water level measurements taken 30 November – 1 December 1999
4. April 2001: 120 water level measurements taken 27-28 April 2001.

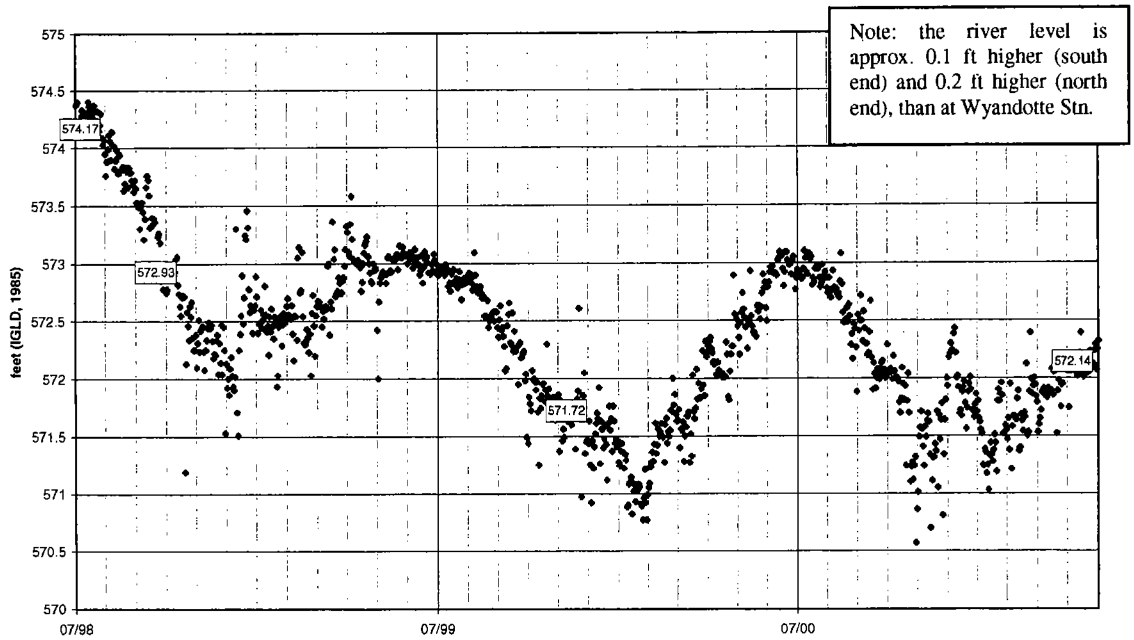
Approximately 25% are screened in the Fill unit, 55% are screened in the Native Sand unit, and 20% are screened across the two units, or the borehole log does not provide adequate information to assess which unit is screened. Where a well is screened across both units, the water level will represent an average value between the potentiometric surface in the Native Sand and the Fill, biased towards the level in the more permeable unit, and with some minor influence from the lower permeability Peat & Clay unit. The average depth to water over these four monitoring events has been 4.2 ft bls for wells screened in the Fill unit or screened across Fill and Native Sand units.

To assess the reliability of the water level data, they were screened for consistency. Exaggerated water level fluctuations were noted in many of the extraction wells, and all of these were removed from the analysis. All remaining data (116 wells) were compared to the criterion that the change in water level relative to the previous monitoring event should generally fall within one standard deviation of the average water level change in all wells. Only two records were eliminated, due to impact from river fluctuations, showing excellent data consistency. Six other records also exceeded the criterion, but these all are located in the area with thick deposits of distiller blow off (DBO) waste. These records were taken to demonstrate the slower hydraulic response of an extensive area of low permeability fill.

The location of monitoring wells and associated hydrostratigraphic unit used in the analysis of the water level data for the site is shown in **Figure 14. Water Level Monitoring Well Locations.** The hydrostratigraphic units have been divided into the categories Fill, Native Sand, and Mixed in this figure, based on the position of the well screen.

3.7.2 Surface Water Elevations

There is no permanent surface water monitoring station at the site. The water level in the Detroit River on the days corresponding to the groundwater level monitoring events may be calculated using data from the adjacent permanent monitoring stations on the Detroit River (Wyandotte, Station 9044030 and Gibraltar, Station 9044020) and interpolating to the location of the site. The site is approximately a mile upstream from the Wyandotte monitoring station. A seven day average was used for model calibration purposes to smooth out daily fluctuations in river level (average 0.24 ft/d), based on the anticipated hydraulic response time of the groundwater system at the site. These data were also used to estimate the average annual water level in the river. See **Graph 1. Water Level Data for Detroit River, Wyandotte Station.**



Graph 1. Water Level Data for Detroit River, Wyandotte Station

3.8 Potentiometric Maps

The potentiometric surface for a geologic unit is the water level (hydraulic head) in a well screened in that unit. As shown in **Figure 14**, wells screened in the Native Sand are distributed throughout the site. Wells screened in the Fill unit are focused along the border with the river, and are largely absent from the interior of the site. Wells screened across both units provide some additional coverage in the central portion of the site.

3.8.1 Native Sand Unit and Fill Unit

Figure 15. Water Level in Native Sand Unit, and **Figure 16. Water Level in Fill Unit**, show the interpolated water level maps (potentiometric surface maps) for these two layers for the April 2001 monitoring event. These plots were prepared using a natural neighbor interpolation algorithm (20 ft cell size, 10 ft aggregation radius, linear surface solution). As noted, the Fill unit group does not contain monitoring wells that cover the central portion of the site or the western border along Biddle.

The extraction wells have not been included in this analysis. Nonetheless, there appears to be a well-defined gradient toward the extraction wells in the Native Sand unit, though only in the extraction wells along Alkali St. ("B" Field). In other parts of the site, there appears to be a slight outward gradient in both the Fill and Native Sand. The unusual groundwater mound first noted in SSPA (1984) in the central eastern portion of the site appears related to the large quantity of fill, specifically of DBO waste, in this area.

3.8.2 Vertical Flow Direction

Ideally, vertical gradients are evaluated using vertically-nested wells covering all areas of the site. An approximate approach, suitable to the data available at the site, is to compare the interpolated potentiometric surfaces for adjacent layers. A plot of the difference in potentiometric surfaces (i.e. interpolated water level in Native Sand minus interpolated water level in Fill), gives a useful impression of the direction of vertical gradients. Positive differences correspond to upward gradients while negative differences indicate downward gradients. As shown in **Figure 17. Vertical Flow Direction**, there is a strong downward gradient in the area of DBO waste, and an apparent upward gradient by the sheet pile seawall east of the DBO waste area. A careful consideration of these data suggests that all conclusions are preliminary due to data scarcity. An evaluation of vertical flow direction could not be made in the central portion of the site, due to lack of well coverage in the Fill.

Vertical gradients are potentially considerable in some areas of the site, though the actual groundwater flux between layers is likely small. Flux depends on hydraulic conductivity, and all data suggest that the Peat & Clay unit, where present, acts as an aquitard between the relatively more permeable Fill and Native Sand units. Note that vertical gradients and flux are likely much higher in close vicinity to the extraction wells, which were not included in the data set for the present analysis.

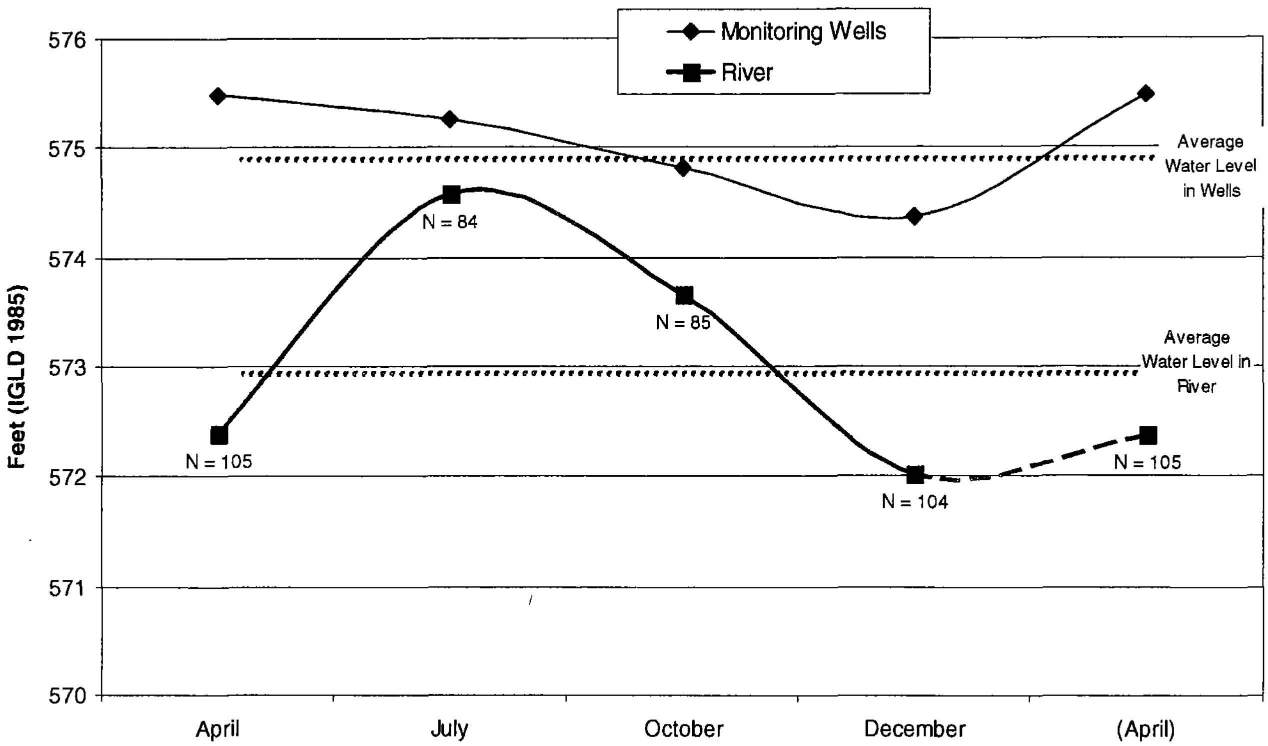
As noted earlier, vertical flow between the Native Sand and Bedrock is reportedly minor (Section 3.1). This is further supported by the reported interconnection between the Bedrock unit and the Detroit River near the site (Section 3.5).

3.8.3 Groundwater Flow Patterns

All site water levels were used to assess groundwater flow patterns at this site. Data for the each of the four monitoring events for all monitored wells are plotted separately in **Figure 18** through **Figure 21**. The data appear to show few changes in the groundwater flow regime over time, despite seasonal fluctuations in water level, i.e. water level varies relatively uniformly across the site due to seasonal recharge fluctuations. The main conclusions from the analysis of these data are that 1) water levels tend to go up and down more or less uniformly across the site, and 2) ground water flow directions are not significantly affected by seasonal variations.

There is a trade-off between precision and coverage in using wells screened across different layers, since vertical head differences are averaged in some areas of the site. The resulting potentiometric maps are useful to evaluate seasonal fluctuations in flow patterns, to better understand if the assumption of longer term steady-state conditions can be applied. For that purpose, we feel that coverage is more important than precision. Mixed unit water level maps, such as those presented in the present section, are not readily suitable to purposes such as evaluating vertical migration potential or precise calibration.

As shown in **Graph 2** below, there is a year round gradient toward the river, with the highest gradient observed in spring. This graph was generated using 1998 to 2001 data, and a similar pattern was noted in February 2002.



Graph 2. Seasonal Fluctuations in Monitoring Wells and River

3.9 Hydraulic Conductivity Estimates

Hydraulic conductivity is usually the single most variable factor in any hydrogeologic investigation. There is considerable hydraulic conductivity data available from prior investigations at the site, most from slug tests on individual boreholes. QST (1999) also report the results of three pumping tests carried out on the Native Sand. An evaluation by PES (2000) provides additional qualitative hydraulic conductivity data regarding the degree of vertical hydraulic connection at the site.

3.9.1 Hydraulic Conductivity Estimates from Field Tests

The geometric mean [$K_G = (K_1 \cdot K_2 \cdot \ldots \cdot K_N)^{1/N}$] is preferred as the measure of the typical value of a variable that is log-normally distributed. If a variable is log-normally distributed, approximately 68% of the samples should lie within ±1.0 standard deviation of the geometric mean. Hydraulic conductivity is commonly taken to be approximately log-normally distributed, and this assumption appears adequate for the North Works site. See graphs of the distribution of $\log_{10}K$ in **Appendix B**, which also contains tables of all hydraulic conductivity data at the site.

Table B1. Hydraulic Conductivity Data for Native Sand Unit, in Appendix B, presents the results from 22 slug tests and 3 pumping tests carried out in the sand unit at the site. These data are plotted in **Figure 22. Hydraulic Conductivity of Native Sand Unit**, using a linear natural neighbor interpolation (20 ft grid). The geometric mean hydraulic conductivity is 2.5 ft/d, and the 1 standard deviation range is 0.4 to 15 ft/d.

Table B2. Hydraulic Conductivity Data for Fill Unit, in **Appendix B**, presents the results from 36 slug tests carried out in the fill unit at the site. These data are plotted in **Figure 23. Hydraulic Conductivity of Fill Unit** (20 ft grid). The geometric mean hydraulic conductivity is 6.6 ft/d, and the 1 standard deviation range is 0.9 to 50 ft/d. This shows more variability than the Native Sand, as was expected for the highly heterogeneous Fill.

Table B3. Hydraulic Conductivity Data for Mixed Units, presents the results from 20 slug tests carried out in mixed or uncertain units at the site. The geometric mean hydraulic conductivity is 4.2 ft/d, and the 1 standard deviation range is 0.6 to 30 ft/d. These values are intermediate to those in the Fill and Native Sand units, as expected. Some of these data may help in defining the distribution of hydraulic conductivity at the site, but the data are not as directly useful as the data from well-defined units.

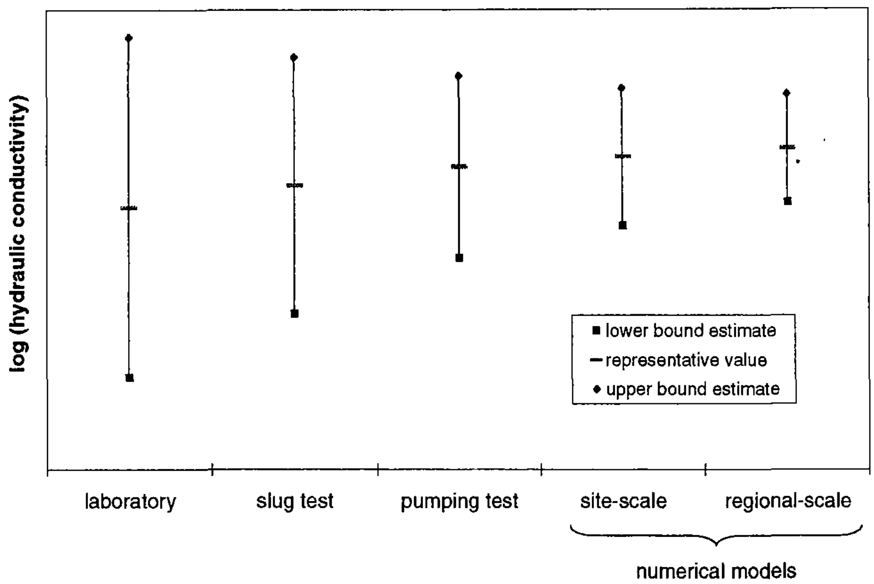
3.9.2 Literature Values of Hydraulic Conductivity

Literature values of hydraulic conductivity are useful to assess the reasonableness of field test data, and also to provide initial estimates for units without field data. Note that the published values of hydraulic conductivity usually refer to horizontal hydraulic conductivity.

Flow through aquitards is generally vertical, and as such, the vertical hydraulic conductivity is more important for fine-grained materials. Horizontal:vertical anisotropy ratios depend on the depositional environment, but are typically in the range of 1:1 to 100:1, with 10:1 being a commonly used value in the absence of test data.

In modeling the North Works site, special care must be exercised for the Native Sand unit, because it can contain clay interbeds that could reduce vertical conductivity.

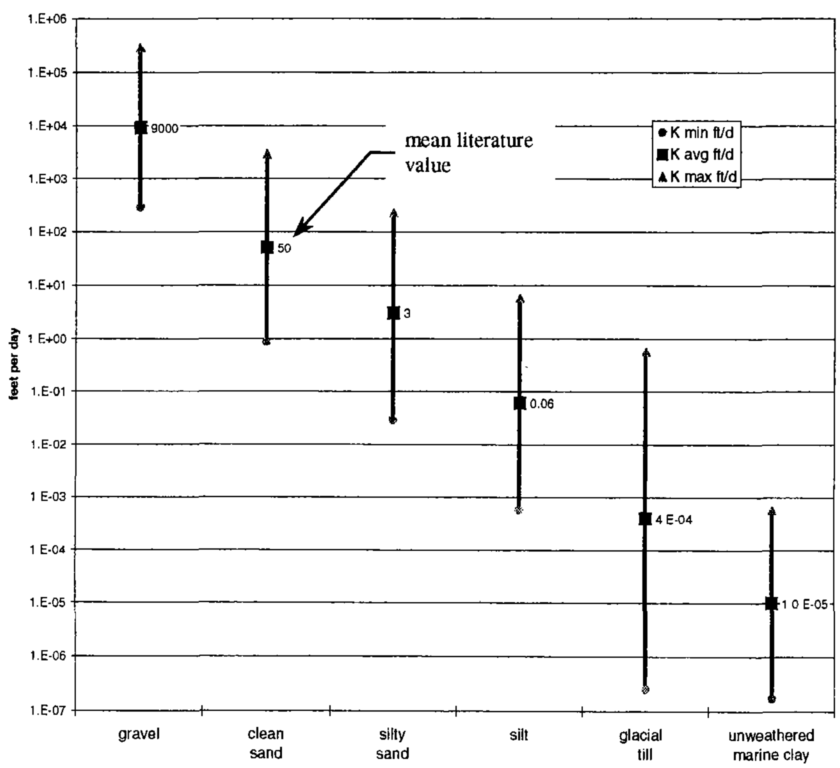
It is commonly observed that hydraulic conductivity is a scale-dependent parameter, and in general, the best representative value for hydraulic conductivity increases with increasing scale. Thus, it is usually found that a point estimate for conductivity from a slug test will be lower than a test that accesses a larger volume of the geologic unit such as a pumping test. Similarly, a groundwater model that encompasses a much larger volume than even a pumping test will tend to have an even higher representative hydraulic conductivity. While conductivity increases, the uncertainty in conductivity tends to decrease with scale. This scale-dependence of hydraulic conductivity is illustrated conceptually in **Graph 3** below.



After Bradbury & Muldoon, 1990

Graph 3. Scale-Dependence of Hydraulic Conductivity

Graph 4. Literature Values of Horizontal Hydraulic Conductivity presents maximum, minimum and average values for sedimentary soils from a standard reference text. The Native Sand (K_{avg} = 2.5 ft/d) most closely corresponds to silty sand. The Fill (K_{avg} = 6.6 ft/d) also falls within the range of silty sand. Some fill, in particular the DBO waste, is likely within the silt range, while other fill materials are more similar to clean sand in their hydraulic behavior.



After Freeze & Cherry, 1979

Graph 4. Literature Values of Horizontal Hydraulic Conductivity

The descriptions of the Peat & Clay unit in the borehole logs support hydraulic conductivity values similar to those for silt or till in **Graph 4**. The Lacustrine Clay unit is expected to correspond to unweathered marine clay, although no hydraulic testing of this unit has been carried out. The final distribution of hydraulic conductivity values was determined through model calibration.

3.10 Spatial Distribution of Hydrogeologic Properties

The distribution of hydrogeologic properties, principally conductivity and storage, greatly affects the flow pattern and hydraulic response at a site. Proper zonation is critical to model calibration. A workable hydrogeologic model must strike an appropriate balance between simplicity (few zones) and complexity (many zones).

QST (1999) suggests:

> This area of thick DBO deposits (Central Area) effectively enables the site to be separated into three general horizontally defined fill areas (i.e., Central Area, South Area, and North Area) in recognition of the hydraulic response of the fill material in each specific area.

This proposed zonation parallels that from SSPA (1986).

QST (1999) states, "Although the thickness of the Clay and Peat Unit is variable, the material properties of the unit appear to remain relatively constant." This is probably the most reasonable starting assumption, given the lack of detailed data on this unit.

In addition to the hydraulic conductivity values, the spatial distribution of hydrogeologic property zones was also determined through model calibration. See Section 6.5.

3.11 Climate

The southeastern Michigan region where the site is located experiences a mid-continental climate, with cold winters and relatively short, hot summers that are regionally moderated by the Great Lakes. The average first frost is October 21 and the average last freezing temperature occurs on April 23. The annual growing season is 180 days. Precipitation averages 30 inches per year, including 16 inches of snow (DNR & OME 1991). Prevailing winds are from 251° (west-southwest), and average 9.7 mph. Climate data for Detroit are included in the HELP model for estimating groundwater recharge. See Section 6.4.

3.12 Recharge

Recharge is the portion of precipitation that reaches the water table, after run-off, evaporation, and transpiration from plants has been extracted.

Impt
SSPA (1984) indicated that the Detroit River potentially acts to recharge groundwater in the southeast portion of the site during concurrently high stages of the river and low groundwater levels. This scenario is most likely to occur during the summer months of June, July, August, and possibly September.

BASF has maintained a pro-active Facility land management program to enhance drainage control capabilities. Ground surface contouring measures are routinely implemented as new needs arise. These measures have reduced recharge to the water-bearing units and associated contact with potential constituents of concern.

Typical values of recharge on shallow-sloped, vegetated surfaces are 10 to 30% of precipitation. At the regional level, recharge is estimated to be 4 to 6 inches/year (data from Holtschlag, 1996), which represents 13 to 20% of average annual precipitation. This agrees with estimated recharge of 4.3 inches per year for the BASF Central Avenue site (ERM, 1981), which is close to the North Works site and has similar stratigraphy. On paved or built-up areas with drains, recharge may approach zero. Built-up and paved areas of the site will have reduced recharge.

The final distribution of recharge zones was determined through a combination of infiltration modeling using the USEPA HELP model, and calibration of the MODFLOW groundwater model of the site.

3.13 Chemicals of Concern in the Contaminant Plume

Although the groundwater model is not expected to be used for contaminant transport, it is prudent to note the contaminants of concern at the site. MDEQ lists the following pollutants at the North Works:

- mercury
- phenols
- dichloroethane
- benzene
- chloroform.

(ref: http://www.deq.state.mi.us/part201ss/ Wayne County, Wyandotte)

Figure 2 shows the Areas of Concern and Solid Waste Management Units at the site. Further details are included in the RFI report (QST, 1999).

3.14 Water Balance and Groundwater Sources and Sinks

(how is [illegible] computed?)

The evaluation of the water balance at the site is one of the main objectives of the present groundwater modeling project. Little detailed information exists, with SSPA (1984) supplying the best information available prior to the current study.

The average (steady-state) water balance from the site may be expressed as:

Water entering site = Water exiting site ± Changes due to chemical reactions

Water enters the North Works from six sources or pathways. They are:

1. Water from the Detroit River (Service Water System), which is used for cooling, washing, etc. The average flow is 6800 gpm (± 10%).
2. Potable water from the City of Wyandotte. The average flow was 880 gpm in 2001
3. Direct precipitation falling on the site, a long term average of about 30.5 inches per year (380 gpm)
4. Diffuse groundwater flow from off-site (no prior estimate available)
5. Diffuse groundwater flow from the Detroit River during high stages of the river (no estimate available)
6. Condensation reactions at the Polyols Plant (no estimate available).

Water leaves the site through thirteen pathways, which are:

1. NPDES regulated Outfall 001. The average flow is 1450 gpm (± 10%) *
2. NPDES regulated Outfall 002. The average flow is 625 gpm (± 10%) *
3. NPDES regulated Outfall 003. The average flow 3300 gpm (± 10%) *
4. POTW regulated Main Gate. The sewer is metered and the average flow is 625 gpm. *
5. POTW regulated Perry Place. The sewer is metered and the average flow is 42 gpm. *
6. POTW regulated Applications Center. The sewer is not metered, but the flow is estimated to be less than < 7 gpm. *
7. Evapotranspiration (including on-site ponds) (no estimate available)
8. Cooling tower evaporation losses (no estimate available)
9. Steam losses to the atmosphere (no estimate available)
10. Surface run off. QST (1999) identified three areas where there was surface run off. (no estimate available)
11. Diffuse groundwater flow to the Detroit River [11 gpm (SSPA, 1984) – See also **Table 6** in the present report for an update of this estimate]
12. Diffuse groundwater flow to Perry Place [0.3 gpm (SSPA, 1984) – See also **Table 6** in the present report for an update of this estimate]
13. Groundwater flow to other off-site areas including drains (no prior estimate available – See also **Table 6** in the present report).

* Note: These regulated discharges may include groundwater infiltration – See also **Table 3** below.

The groundwater portion of the water balance is of primary interest for this project. It is clear from the range of values presented that a useable groundwater balance cannot be derived from these figures. For example, the uncertainty in item 1 (Service Water System: ±10% of 6800 gpm = ±680 gpm) far exceeds the estimate of total diffuse outflow to the Detroit River (11 gpm). Given the opportunity for error in water balance calculations from numerous meters measuring large volumes of water, and the anticipated small rate of groundwater discharged from the site, an overall water balance was not attempted.

The long-term average ***groundwater*** balance can be expressed as:

Net recharge = groundwater infiltration into sewers + groundwater extracted + net diffuse flow

EPA's HELP model was used in conjunction with previous regional studies to estimate net groundwater recharge (precipitation – surface run-off – evapotranspiration – lateral drainage). Water losses to groundwater from the fire protection piping and steam traps were ignored.

The location and condition of sewers in the numerical groundwater flow model of the site is based on engineering plans from BASF and the City of Wyandotte. Groundwater infiltration into sewers has not been measured, but was estimated using the computer model (see Section 6.3).

The groundwater extraction and treatment system is comprised of 15 pumping wells organized into three well fields, denominated A, B, and C (see **Figure 2**). It has been operating since 1986. All wells are screened in the native sand unit. Extracted water is treated on-site and discharged to a POTW. Early extraction rates (1987) were approximately 1900 ft^3/d, but the system currently operates at less than 1000 ft^3/d. Operational difficulties have been noted due to accumulation of fines and chemical deposition, leading to low well efficiency. BASF has replaced most wells since 1997, and longer stainless steel screens were substituted for the original 2-foot carbon steel screens. The overall volume of groundwater extracted is metered.

Water may also seep from the river easterly during high stages of the river and low stages of the water table, generally in June, July, August, and possibly September. A small quantity of water may also cross the northern, western, and/or southern boundaries of the site.

The method SSPA (1984) used to estimate average ground-water discharge from the site was based on transmissivity of the surficial materials and hydraulic gradients at average, high and low water levels. **Table 3** below presents the results of this analysis. A similar transmissivity-based approach was used in the 2002 Field Program (WHI, 2002) and the results from this updated estimate of groundwater flux were used in calibrating the numerical MODFLOW model of the site. See Section 7.3 and **Appendix D**.

Table 3. Average Rate of Groundwater Discharge from the North Works Site in 1984

	Groundwater Discharge (ft^3/d)
Diffuse flow to the Detroit River	2,160
Diffuse flow to Perry Place	60
Total uncontrolled discharge	2,220
NPDES regulated Outfall 001	2,200
NPDES regulated Outfall 003	1,080
City Sewer System (POTW)	1,980
Total controlled discharge	5,260
Total discharge	7,480

Note: These data are for comparison purposes only. Numerous changes to the groundwater flow system at the site have taken place since 1984, starting with the installation of the groundwater extraction system in 1986. For updated estimates based on current conditions, see **Table 6**.

4.0 Conceptual Model Summary

MDEQ defines **model conceptualization** as:

> the process in which data describing field conditions are assembled in a systematic way to describe groundwater flow and contaminant transport processes at a site. The model conceptualization aids in determining the modeling approach and which model software to use.

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Decisions made at the conceptual model stage are difficult to correct later on, so it is vital that these issues be granted the necessary care. Typical factors relate to the model domain, hydrogeologic boundaries, and uncertainty. A checklist serves both to summarize information and to help ensure model QA/QC.

4.1 Conceptual Model Checklist

Question	Response
1. Are there adequate hydrogeological data to describe the conditions at the site?	Very good data exist for analyzing flow conditions at the site, under ambient and pumping conditions. Considerable data exist on contaminant distribution at the site, but this data is not sufficient to fully characterize contaminant distribution and transport processes. No modeling of contaminant transport is proposed for the site.
2. In how many directions is groundwater moving?	Groundwater appears to flow onto the site from the west, along Biddle Ave. There is a mound in the northern central part of the site, causing some flow toward the Detroit River. The flow regime in the southern portion of the site is less certain. Flow velocities appear to be very low south of Alkali St Ground-water flow near the three extraction well fields is toward the wells, with strong downward gradients from the overlying fill.
3. Can the groundwater flow or contaminant transport be characterized as one-, two- or three-dimensional?	The clay interbeds in the sand and the presence of the Peat & Clay between the fill and sand promote horizontal flow, but the active extraction system produces strong vertical gradients. As such, the groundwater flow regime is characterized as three-dimensional.
4. Is the aquifer system composed of more than one aquifer, and is vertical flow between aquifers important?	The Fill and Native Sand units act as aquifers and are separated in most parts of the site by a Peat & Clay aquitard unit. Vertical flow between the aquifer units may be important, especially under pumping conditions. The aquifers are unconfined where the Peat & Clay is absent.
5. Is there recharge to the aquifer by precipitation or leakage from a river, drain, lake, or infiltration pond?	Recharge occurs from precipitation, and possibly from the river under certain conditions. Groundwater may also enter the site from its western boundary along Biddle Avenue. There are two ponds on-site, but they are lined and should not contribute to groundwater recharge.
6. Is groundwater leaving the aquifer by seepage to a river or lake, flow to a drain, or extraction by a well?	Groundwater leaves the site through the extraction well system, with additional seepage to the river and to drains within and around the site.
7. Does it appear that the aquifer hydrogeological characteristics remain relatively uniform, or do geologic data show considerable variation over the site?	Geologic data show considerable variation over the site, though the stratigraphy is well defined. The Fill is continuous and very heterogeneous. The Peat is discontinuous. The Native Sand pinches out along the River, but is relatively homogeneous. The Lacustrine Clay is continuous and homogeneous.
8. Have the boundary conditions been defined around the perimeter of the model domain, and do they have a hydrogeological or geochemical basis?	The boundary conditions are well defined around the model domain. The boundaries to the north, east, and south are physical boundaries as part of the Detroit River. The western boundary condition is also believed to be physical, as the Native Sand and Fill units thin in that direction.
9. Do groundwater flow or contaminant source conditions remain constant, or do they change with time?	Groundwater flow conditions change over the course of the year, reflecting river stage and recharge fluctuations. However, the general flow patterns have been observed to be stable throughout the year.
10. Are there receptors located generally down-gradient of the contaminant plume?	The principal down-gradient receptor is the Detroit River. A secondary receptor is the Wayne County Sewer System.
11. Are geochemical reactions taking place in on-site groundwater, and are the processes understood?	Geochemical processes are complicated due to the site's industrial history, and as such are not completely understood.

4.2 Model domain

The model domain relates first to the scale of the model. Common though somewhat arbitrary distinctions include:

- regional scale – site less than 25% of the total model domain
- local scale – site greater than 25% of the total model domain
- site scale – site approximately coincident with total model domain
- sub-site scale – model domain less than size of site.

The rather unique geologic setting of the site isolates it from the surrounding region to such an extent that a site-scale model is appropriate. This greatly limits the requirements for off-site data. However, potential contaminant sources on-site are sufficiently dispersed to eliminate consideration of sub-site scale modeling. The model was extended to the west side of Biddle Avenue to incorporate the effect of the deep sewer located at the north end of the site (see **Figure 2**).

4.3 Model layers

From all available information, the lacustrine clay deposit that underlies the site is extensive and its permeability is sufficiently low to qualify as impervious for the purposes of flow modeling. The Fill and the Native Sand units form the two relatively permeable units at the site. The low conductivity Peat & Clay deposit is an important aquitard, which limits, but does not eliminate contaminant transfer between the upper fill and the lower sand. Where the Peat & Clay unit is not continuous (see **Figure 7**), "windows" facilitate interaction between the upper Fill and lower Native Sand units.

Because the lacustrine clay isolates the deeper dolomitic aquifer from the surficial units, the deeper aquifer system was not included in the present groundwater model. The lacustrine clay unit is included as the bottom layers in the model. It was used in a sensitivity analysis context in the numerical modeling, i.e. to verify the assumption that waters are effectively segregated into an upper groundwater system and a deeper groundwater system. This layer is also needed to simulate facilities incised in it (see Section 6.1).

4.4 Hydrogeologic boundaries

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The water level in the Trenton Channel of the Detroit River provides the eastern geological boundary of the model. The marinas to the north and south of the site bound the upper layers of the model. The western boundary is the rising surface of the Lacustrine Clay unit, effectively limiting the possible flux of groundwater from or to the site. Sewers along Perry Place, Biddle Avenue, and Mulberry Avenue also act as hydrogeologic boundaries (drains).

4.5 Data sources and uncertainties

With respect to data sources and uncertainties, it is assumed that the information provided by previous studies at the site is reliable and as such provides a good site characterization. In the absence of well logs, sewer records provide useful information regarding off-site conditions.

Detailed information on abandoned underground conduits and drainage ditches, especially where they may lie below the water table, is not available. Bedding, backfill, and infiltration details for the storm sewers on Biddle Avenue are unknown. Underground conduits and their surrounding bedding material (granular backfill) may provide preferential pathways that affect both flow and transport of contaminants. Their impact is limited as long as hydraulic control is maintained, but consideration of alternative remediation strategies could bring into question the need for more detailed characterization of underground drains.

No explicit modeling of underground conduits is expected to be necessary, with the exception of larger sewers that are modeled as drains. Some analysis may be undertaken using the calibrated model to construct a "what if" scenario to assess the validity of this assumption at a later date, though experience at other sites indicates that they will not play a major role.

The hydrogeologic properties of the Fill, are highly variable, and even the Native Sand shows considerable variability (see Appendix B). The hydraulic behavior of the seawall is also unknown. These uncertainties were evaluated using professional judgment based on interpretation of borehole logs, observation of soil samples, and assessment of engineering plans, and evaluated during model calibration and sensitivity analysis.

Regarding the stratigraphic characterization of the site, there are uncertainties caused by the fluvial depositional environment and by anthropogenic activities on-site to be evaluated during model development. These uncertainties relate to:

1. the location, depth, and fill characteristics of man-made incisions into the Lacustrine Clay, such as the historic shipyard channel;
2. the location of an outlet from the historic channel in the Lacustrine Clay naturally eroded by the extinguished river meander;
3. continuity and connectivity of lenses or interbeds in the native materials.

The results of the February 2002 Field Program reduced, but did not eliminate, these uncertainties.

5.0 Numerical Modeling Approach

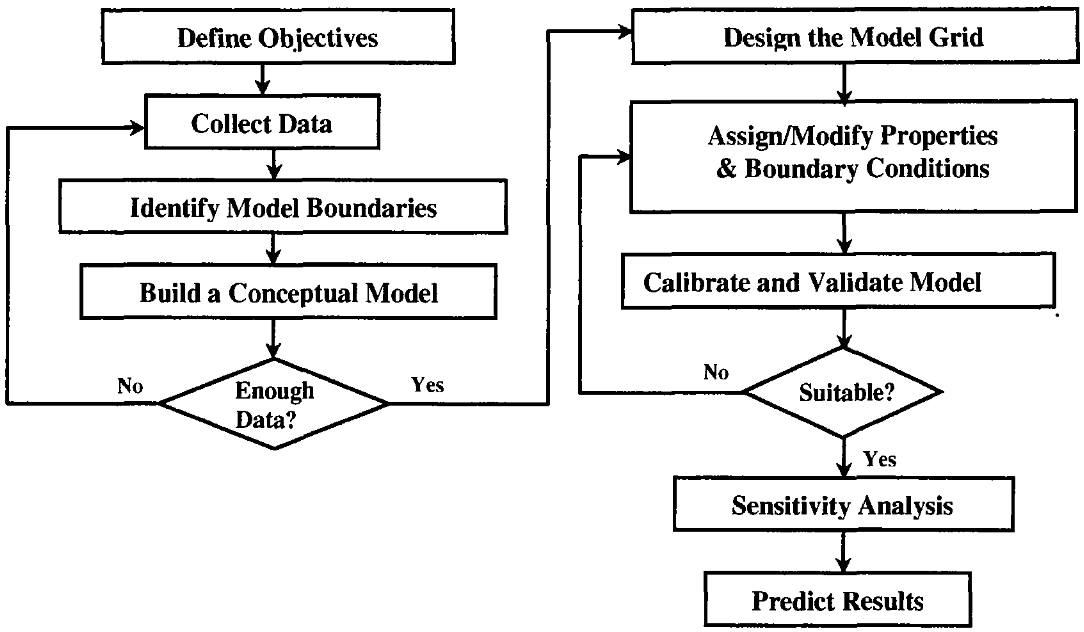
Based on the conceptual model as described above, WHI has developed an appropriate approach for developing a groundwater model for the BASF North Works site, as described in the following sections. To summarize:

- A three-dimensional finite difference code (MODFLOW) was used to simulate steady-state conditions at the site.
- Layer thicknesses were derived from existing interpretations of borehole logs.
- Estimates of hydraulic conductivity were derived slug tests and pumping tests at the site.
- Recharge estimates derived from the USEPA HELP code, and existing land uses at the site.
- Boundary conditions are based on observed water levels in the Detroit River and observed water levels in on-site wells.
- Drain locations and elevations were extracted from engineering plans for public works and for the site itself.
- Groundwater extraction rates are based on observed total current treatment volumes for the site.

The numerical model was calibrated to average water levels from four monitoring events, and estimated boundary flows from one monitoring event. No alternative stress condition was judged appropriate for model verification.

5.1 Groundwater Model Development

Groundwater modeling development and application requires a systematic approach that follows the logical steps outlined in **Graph 5** below.



Graph 5. The Groundwater Modeling Process

These phases are discussed in sequence below.

5.2 General modeling approach and numerical code selection

The numerical code for modeling must be appropriate for all simulated scenarios. The general approach was to develop the model and calibrate to long-term average conditions. The groundwater modeling was implemented with a three-dimensional flow model using the USGS MODFLOW finite difference code. It is appropriate for the likely remedial controls at the North Works Facility.

6.0 Model Implementation

Implementation encompasses development, calibration, verification, and sensitivity analysis. Model development issues include grid orientation and discretization (areal and vertical), boundary conditions, and hydrogeological parameters. Calibration and verification issues deal with head calibration statistics and water budgeting.

6.1 Model Layers

The implementation of the model in MODFLOW uses five layers. It does not include the Bedrock unit, but subdivides the Lacustrine Clay to more accurately represent the facilities such as utility trenches that are incised into this unit. See **Figure 24** and **Figure 25**.

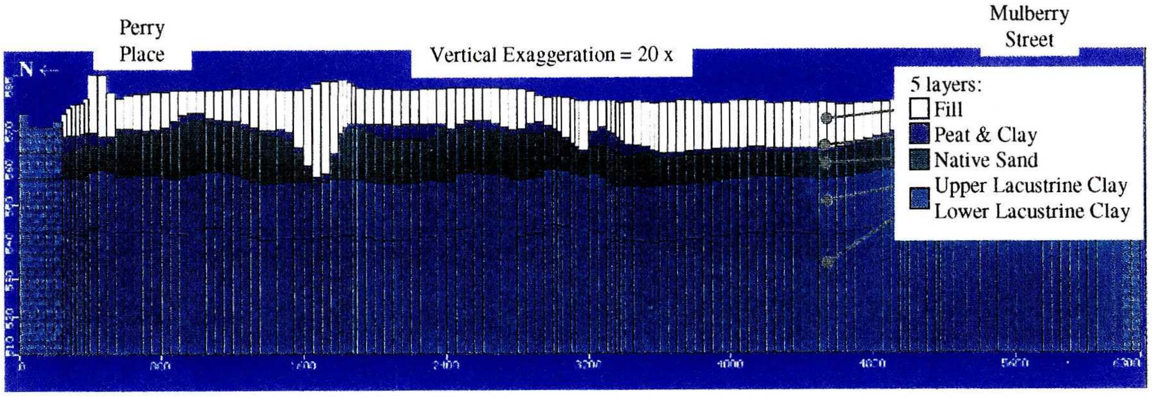


Figure 24. Vertical Grid Discretization (Layers) – North-South

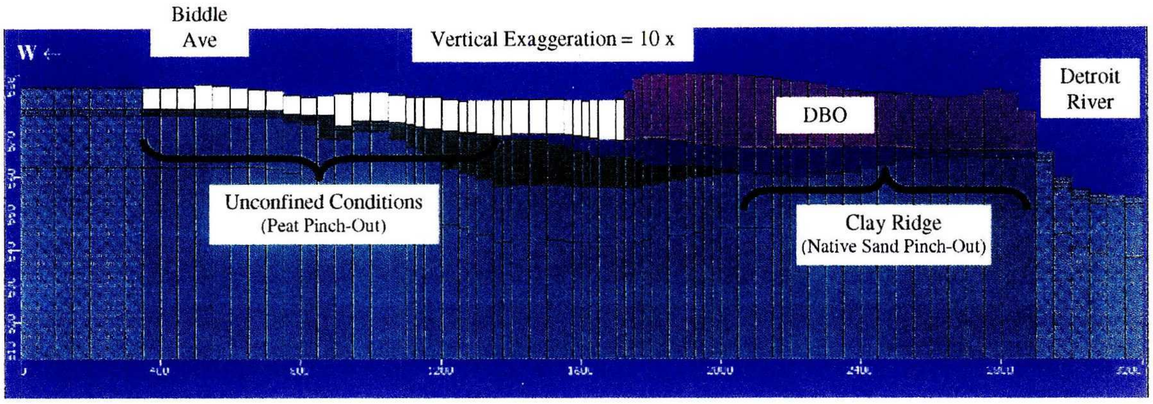


Figure 25. Vertical Grid Discretization (Layers) – West-East

6.2 Areal Grid

The logical areal (horizontal) grid orientation is north-south roughly parallel to the Trenton Channel and Biddle Avenue. Given the domain size and complexity, the grid is shown in **Figure 26. Model Domain and Model Grid**, with additional refinement at important features such as existing extraction wells.

Note that model coordinates do not match site coordinates. The point (N 3500, W 1200) in site coordinates corresponds to the model origin (0.0). Model coordinates are rotated clockwise 0.84 degrees with respect to site coordinates. The model is 6300 feet long and 3200 feet wide.

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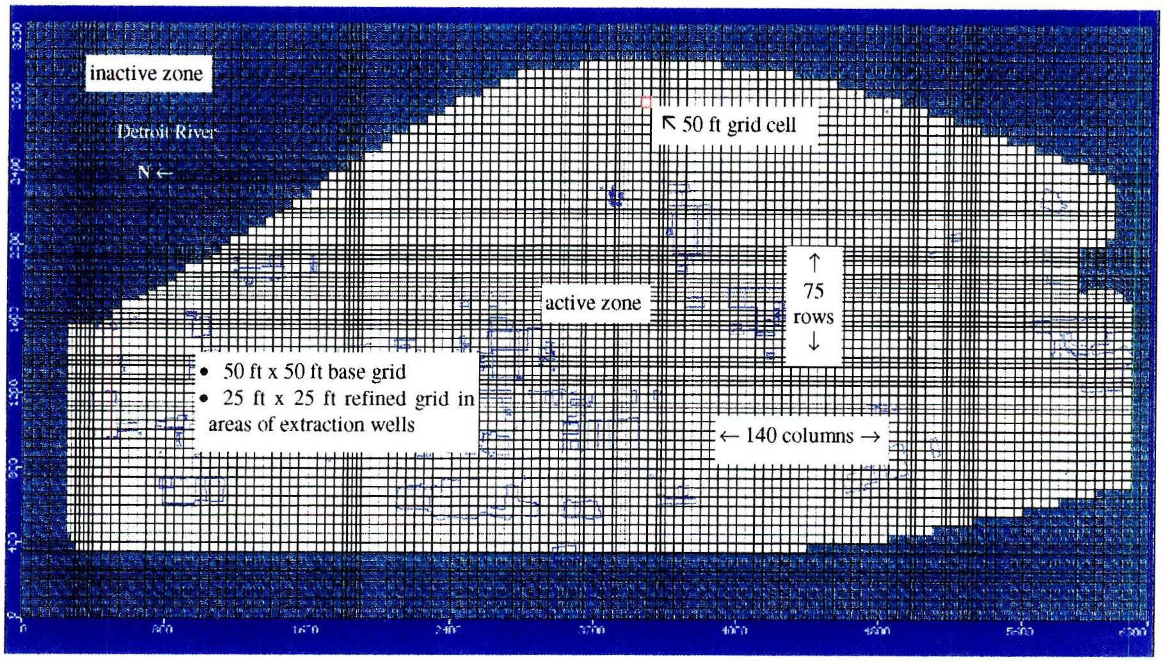


Figure 26. Model Domain and Model Grid

6.3 Boundary conditions

The boundary conditions where the model intersects surface water and there is no deep seawall present (southern portion of the site beside the Detroit River to east, marinas to north and south) is a specified (constant) hydraulic head (1st type or Dirichlet boundary condition– see **Appendix D**) defined by the average water level in the river.

The groundwater levels (**Figure 18** to **Figure 21**) indicate a head dependent flux boundary (3rd type or Cauchy boundary condition – see **Appendix D**) where deep sea walls exist. Conductance values for this boundary are based on construction plans for the various phases of the sea walls, field observations, and model calibration. As the sea walls were constructed at different times, it was expected that conductance values would not be uniform, and this is borne out in the observed water levels and calibrated model. Head dependent flux boundaries are termed "general head boundaries" (GHB) in MODFLOW.

The boundary condition on the far (western) side of Biddle Avenue is implemented with a head dependent flux boundary chosen to match the observed on-site gradient. The reference head (H_{REF}) for this boundary was calculated by projecting the observed gradient back a distance of 500 ft from the western limit of the model domain. Conductivities for this boundary are based on cell area and hydraulic conductivity. This head dependent flux boundary applies to the upper three model layers, with the lower two model layers (Lacustrine Clay) being modeled as no flow boundaries.

The portions of the northern (Perry Place) and southern (Mulberry Street) boundaries that are not in direct contact with surface water (i.e. the portions west of the respective marinas) are modeled as no flow boundaries in all layers.

These exterior boundary conditions are illustrated on **Figure 27. Exterior Boundary Conditions**.

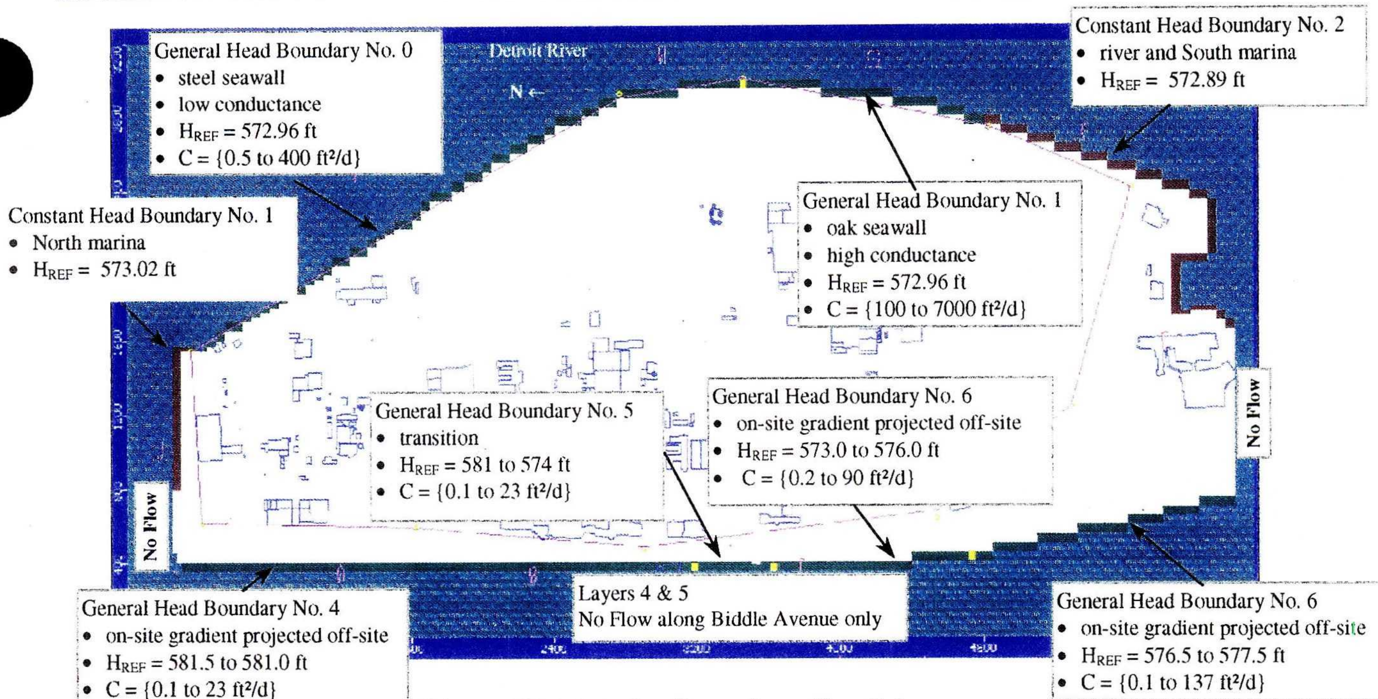


Figure 27. Exterior Boundary Conditions

Inside the model domain, flow is affected by sewers below the water table that function as drains, and by the groundwater extraction system. Groundwater infiltration into sewers was estimated from BASF's knowledge of the condition of the sewer systems, and was calibrated to observed water levels. As implemented in MODFLOW, drains can only collect water. That is, infiltration to sewers is modeled, but exfiltration is not. Additional data regarding drains is contained in **Table 4**.

Table 4. Drain Database

Drain No.	Description	Length (ft)	Layers	H_{REF} (ft IGLD85)	Conductance (ft²/d)	Model Infiltration* (ft³/d)
1	abandoned Perry Place sewer	900	1	573.8…574.7	0.8…8	23
2	deep North Biddle sewer	960	4	562.3…562.7	0.5	94
3	shallow North Biddle sewer	1400	1…4	575.2…577.6	0.2	24
6	shallow South Biddle sewer	850	1	571.0	0.4..1.3	64
7	Police Stn. sewers	600	3…4	569.0	1…3	241
10	Mulberry St. sewers	1150	3…4	572.0…576.0	0.5…1	22
11	abandoned sewer Northline ext.	2200	1…2	570.0	0.5…1	132
13	abandoned ditch behind Police Stn.	850	1…3	571.5	6…20	508
14	box sewer EW along Alkali St	1550	1	570.5…569.5	6…16	1898
15	box sewer NS section	200	1	572.9…570.5	20	
	Total	**10660**				**3006**

* Note that these infiltration estimates are based on output from the numerical model, not observed values.

The groundwater extraction system is modeled directly using MODFLOW's well routine. There are 15 groundwater extraction wells and 15 corresponding model wells. These boundary conditions are illustrated on **Figure 28. Internal Boundary Conditions**.

Groundwater recharge, which may be considered an exterior boundary condition (2nd type or Neuman boundary – see **Appendix D**), is discussed in Section 6.4.

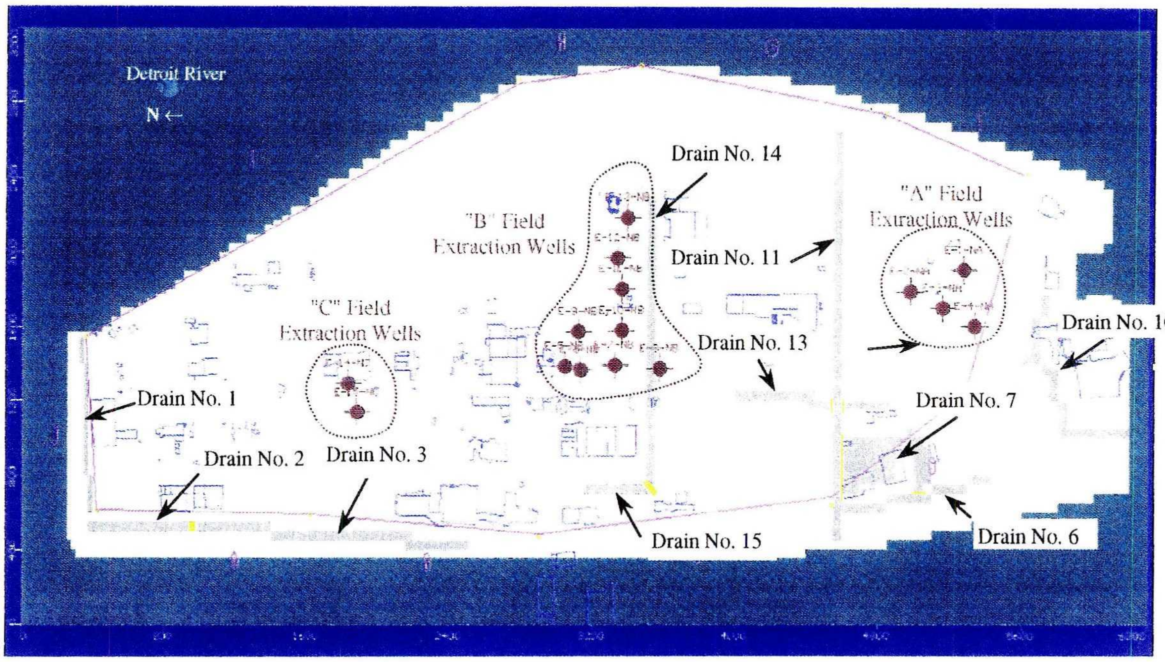
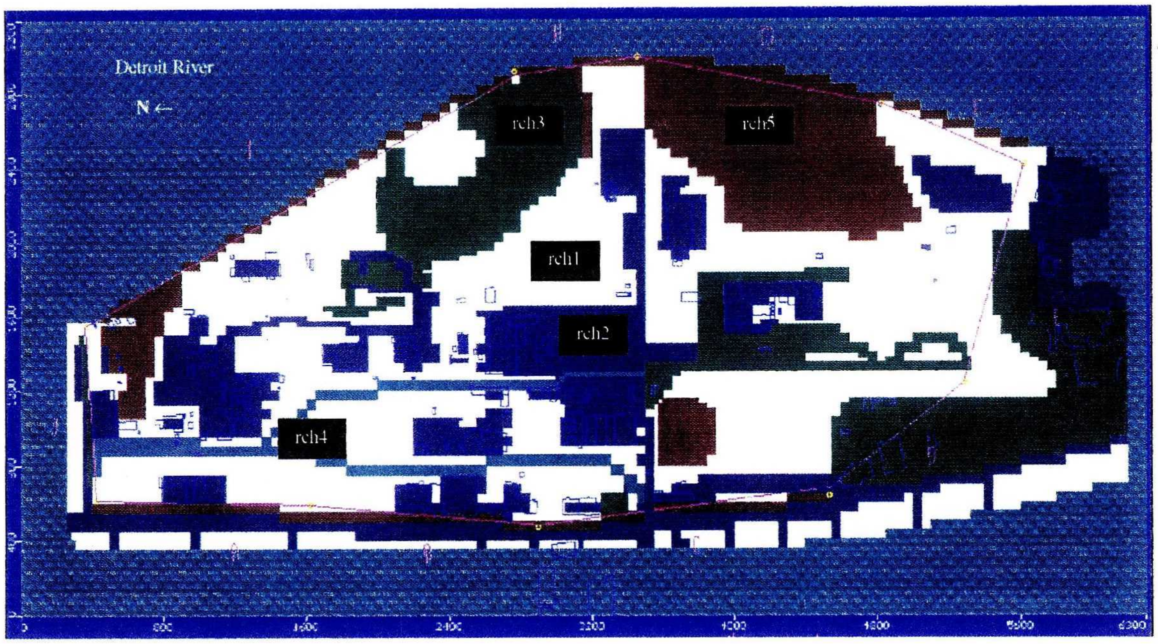


Figure 28. Internal Boundary Conditions

6.4 Recharge

Groundwater recharge is important at the North Works site, since approximately 2/3 of the site is unpaved. At the regional level, net recharge is estimated to be 4 to 6 inches/year (Holtschlag, 1996). Infiltration at the site was estimated using regional meteorological data and the USEPA HELP code to establish profile-specific predictions of recharge flux in permeable land-use zones (3.0 to 6.6 inches/year).

Recharge modeling at the North Works site requires consideration of specific land uses and drainage conditions. Recharge zones were assigned using five different recharge levels. See **Figure 29. Recharge Zones**. Final calibration produced values within the same range as those predicted by the HELP model and regional studies. The average recharge on permeable zones is 3.9 inches per year.



Zone	Color	Description	area million ft²	recharge rate inches/year
rch2		Paved/Built Areas	2.8	0.15
rch3		Low Recharge	2.2	0.50
rch1		Normal Recharge	5.6	3.4
rch5		Ponded Areas	1.8	5.0
rch4		High Recharge	0.3	7.1

Figure 29. Recharge Zones

6.5 Hydraulic Conductivity

Hydraulic conductivities were originally based on estimates from **Figure 22** and **Figure 23,** and were refined during calibration (see Section 3.9 and **Appendix B**). The default ratio of horizontal to vertical conductivity (K_H/K_V) is 10:1. This ratio was varied for fill materials, such that K_H/K_V was reduced to account for loose fill (4:1) and increased to account for heterogeneous zones of fill (20:1).

Figure 30 through **Figure 33** below show the distribution of horizontal hydraulic conductivities for Layers 1 through 4 in the numerical model. Layer 5 (not shown) is composed of Lacustrine Clay (K_4).

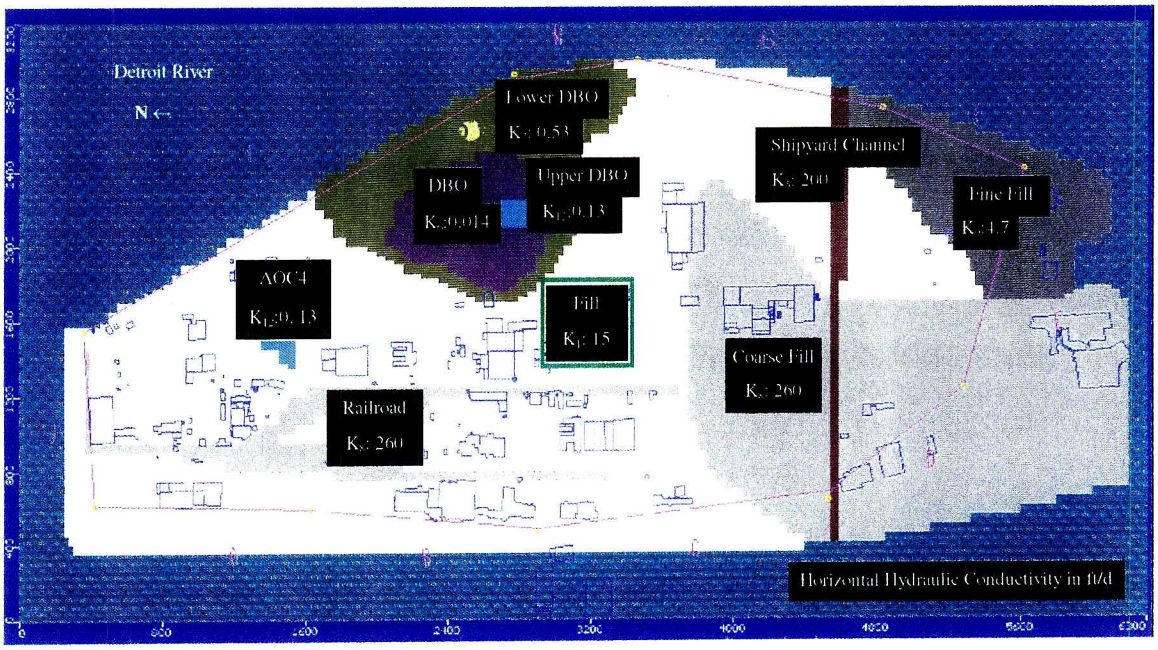


Figure 30. Conductivity Zones in Fill (Layer 1)

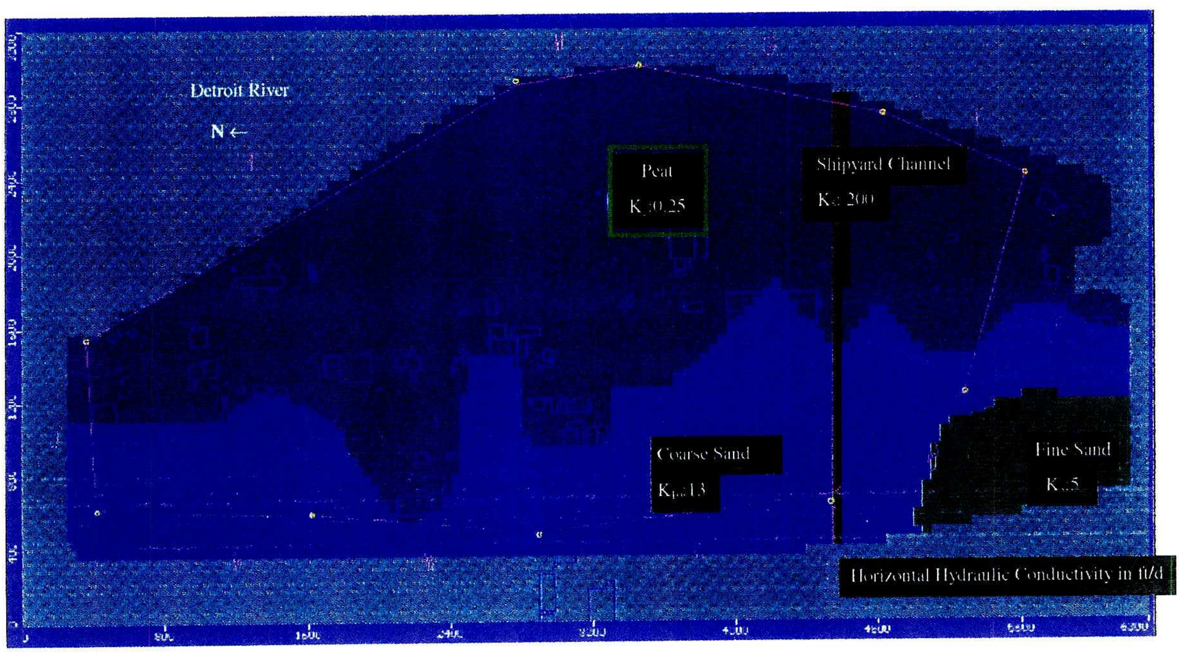


Figure 31. Conductivity Zones in Peat & Clay (Layer 2)

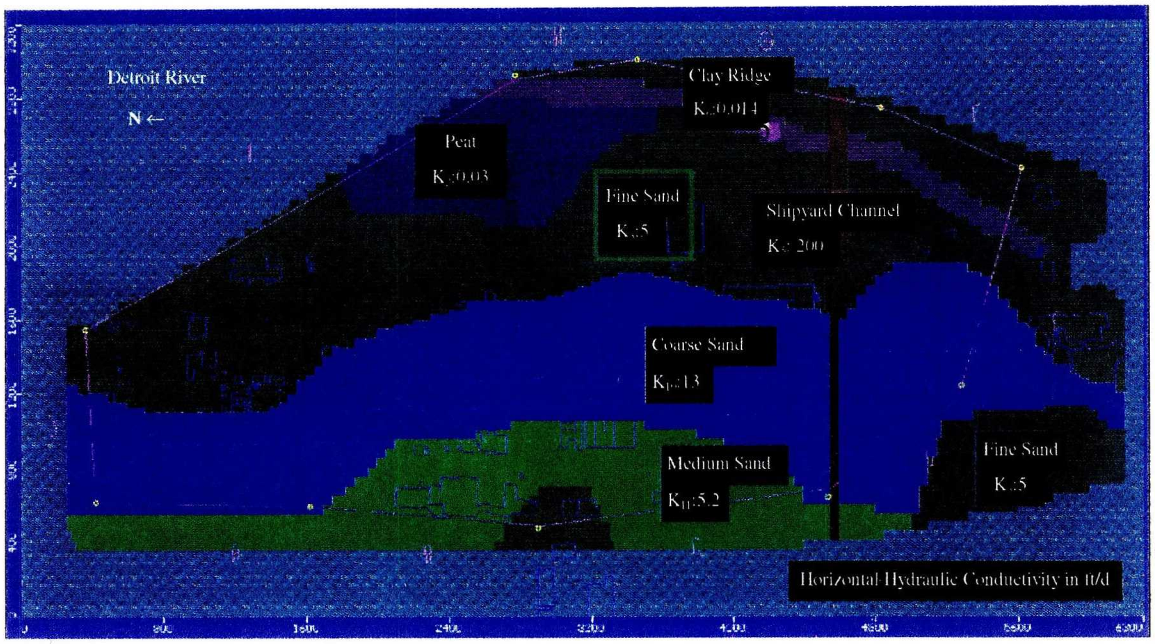


Figure 32. Conductivity Zones in Native Sand (Layer 3)

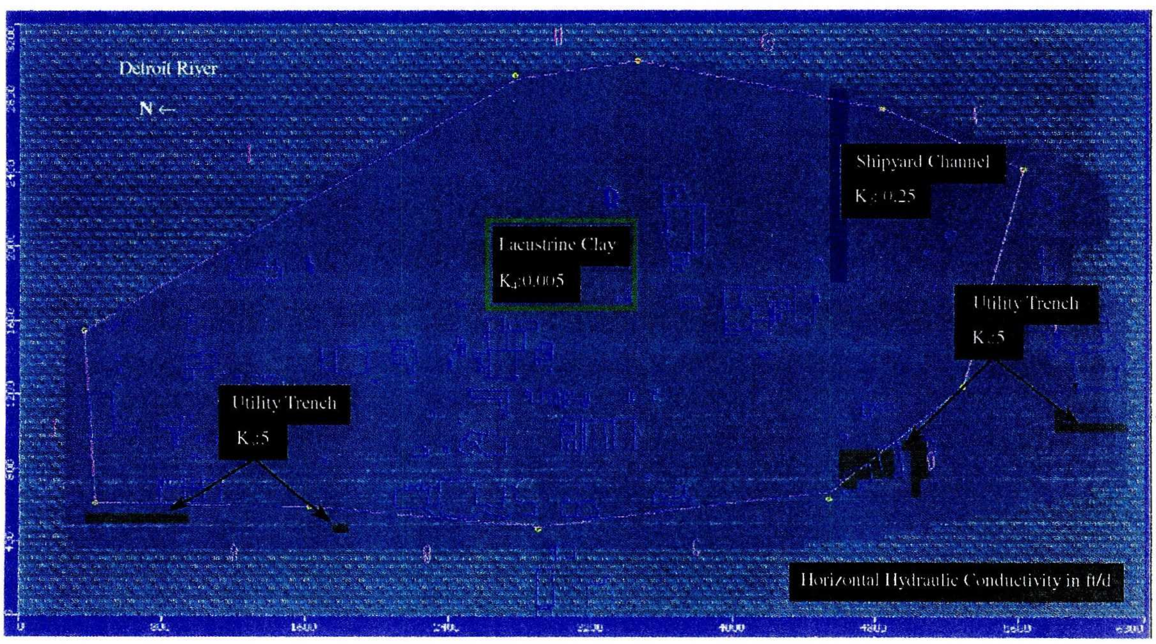


Figure 33. Conductivity Zones in Lacustrine Clay (Layer 4)

Table 5 below contains all data on conductivities in the model. Note that all materials are modeled as being horizontally isotropic ($K_X = K_Y$).

Table 5. Conductivity Zone Database

Zone	Color	Description	$K_X = K_Y$ ft/d	K_Z ft/d	Kx:Kz
9		Fine Fill	4.7	1.2	4
1		**Fill**	15	3.9	4
8		Coarse Fill	260	66	4
12		Upper DBO	0.13	0.0064	20
6		DBO	0.014	0.0014	10
7		Lower DBO	0.53	0.053	10
5		Shipyard Channel	200	20	10
2		**Peat**	0.25	0.025	10
3		**Fine Sand**	5	0.5	10
11		Medium Sand	5.2	1.0	5
10		Coarse Sand	13	1.8	7
4		**Lacustrine Clay**	0.005	0.0005	10

Figure 34 through **Figure 37** below show the conductivity distribution in cross-section. These views provide important information on layer continuity that is not easily distinguishable in plan view.

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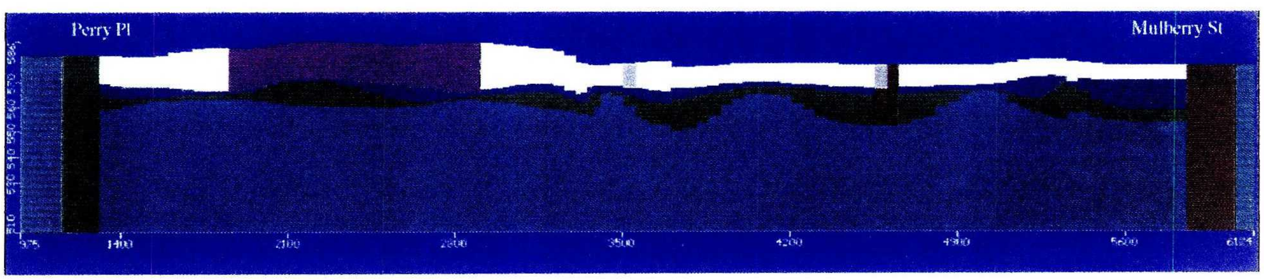

Figure 34. Typical North-South Section

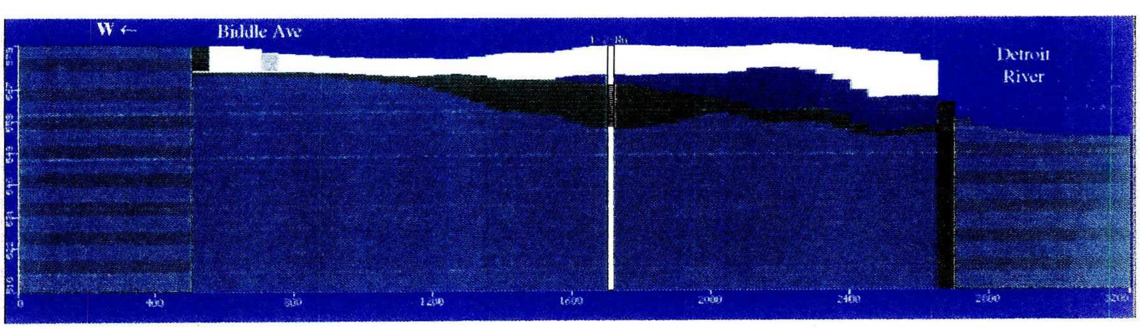

Figure 35. Typical West-East Section through "A" Field Extraction Wells (South)

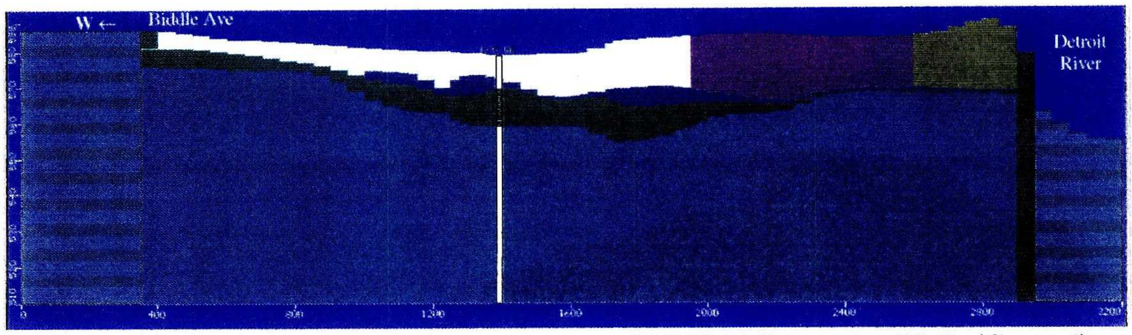

Figure 36. Typical West-East Section through "B" Field Extraction Wells (Central)

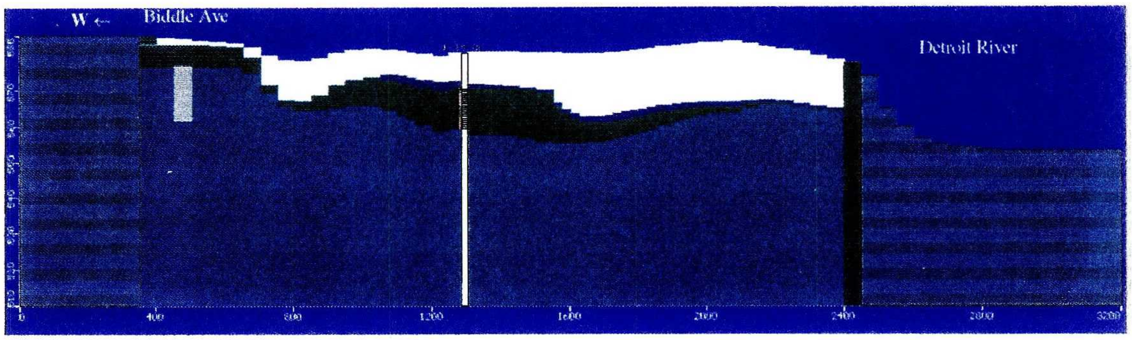

Figure 37. Typical West-East Section through "C" Field Extraction Wells (North)

6.6 Storage

The most important storage parameters for transient simulation are the specific storage coefficient and the specific yield. Pumping test data and professional judgment were used to estimate reasonable values for these parameters. For the Native Sand, QST (1999) estimate the following zones of storativity:

- North: Estimated storativity is 0.002
- Central:Estimated storativity is 8×10^{-6}
- South: Estimated storativity is 0.002.

Note that the model has only been used to analyze steady-state flow conditions, under which storage plays no role, as there is no change in storage for a steady-state condition.

6.7 Effective Porosity

Effective porosity is used with particle tracking to estimate groundwater and contaminant velocities and time-of-travel calculations. Professional judgment was used to estimate these parameters, since no direct estimates are available from the site data. Initial estimates are 0.25 for the Native Sand, 0.1 for the Peat & Clay, and 0.3 to 0.5 for the Fill.

7.0 Model Calibration

A good calibration is essential to obtaining a realistic and defensible model. One of the primary indicators of calibration is the comparison of predicted heads to those observed in monitoring wells. One of the goals is to have a low normalized root mean square residual (NRMS). Calibration to a NRMS of less than 10% is a commonly accepted criterion. Another calibration goal is to have the mean residual (the mean difference between simulated and measured heads) less than 0.5 ft. Hydraulic head residuals (simulated minus observed heads) are plotted as distributed bubble plots and in histogram format to analyze potential bias in areas of the model domain.

Two separate calibrations were undertaken. The first was to average water level under steady-state pumping conditions (July 1998 to April 2001 data). The second was to a weighted combination of these same average water levels and a boundary flux estimate based on results of the February 2002 Field Program. Verification to an alternate steady-state condition (such as the pump shut-down test conducted in August 1997) was not possible due to lack of reliable data. If further data becomes available, verification to another stress condition may be possible. Data from SSPA (1984) could not used because of numerous changes to the hydrogeological conditions at the site, such as site grading to improve drainage, installation of the groundwater extraction system, revisions to underground drains, etc.

Impt. * The incorporation of flow estimates, based on observed values of hydraulic gradient, hydraulic conductivity, and unit thickness, provides an important check on model realism. By incorporating this groundwater flow information into the calibration, the non-uniqueness of the model has been reduced, effectively achieving the same purpose as model verification.

The preliminary calibration to water levels was successful, and produced an excellent match between observed and modeled water levels (NRMS = 3.6%). However, recognizing the problem of model non-uniqueness[1], WHI recommended in December 2001 that additional water level data be collected, in particular around the boundary of the site. These additional data were collected in February 2002 and the results have been incorporated into the numerical groundwater flow model.

Impt. * Incorporation of the flow estimates required adjustments to the values of hydraulic conductivity and recharge. The second calibration was also successful (NRMS = 5.1%), and correctly predicted flow directions in both the Fill and Native Sand layers for each of 10 segments around the boundary of the site. The following sections present the calibration data.

7.1 Predicted Water Levels and Flow Directions

One key objective of the North Works flow model is to reliably predict flow directions and rates. **Figure 38. Predicted Water Levels and Flow Velocities – Fill Unit** and **Figure 39. Predicted Water Levels and Flow Velocities – Native Sand Unit** in **Appendix A** illustrate modeled water levels and resulting velocities at the site. These two figures provide probably the best overall view of the model results. Note that the average flow velocity in the Native Sand is approximately double that in the Fill, and that the velocity in the Lacustrine Clay is negligible.

[1] In geological interpretation and mathematical modeling, a problem for which two or more models satisfy the data equally well.

The following figures (**Figure 40** through **Figure 42**) illustrate predicted water levels and flow directions in cross-section through the three extraction well fields. An interpretation of apparent capture zones is included for the extraction wells – the capture zone is only apparent because flow is three-dimensional.

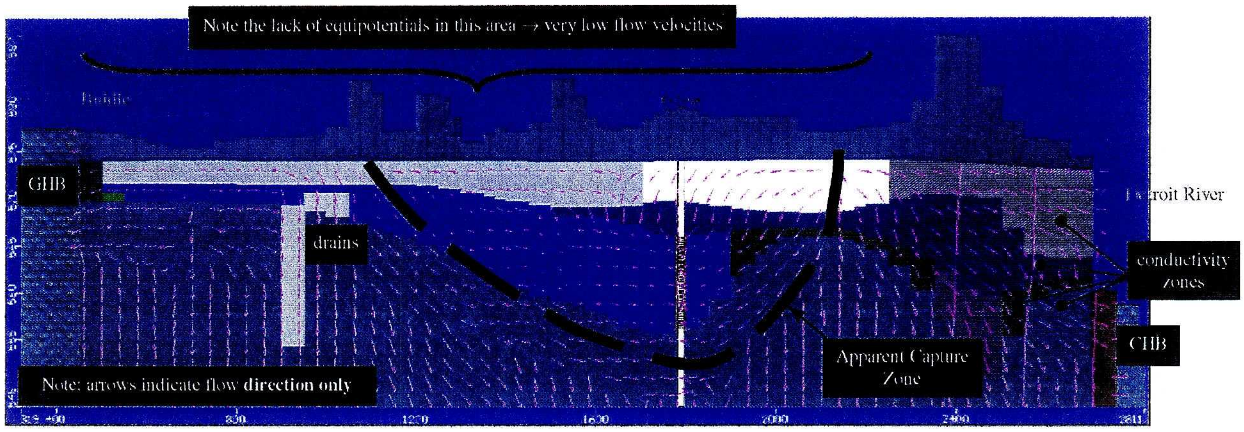

Figure 40. Flow for West-East Section through "A" Field Extraction Wells (South)

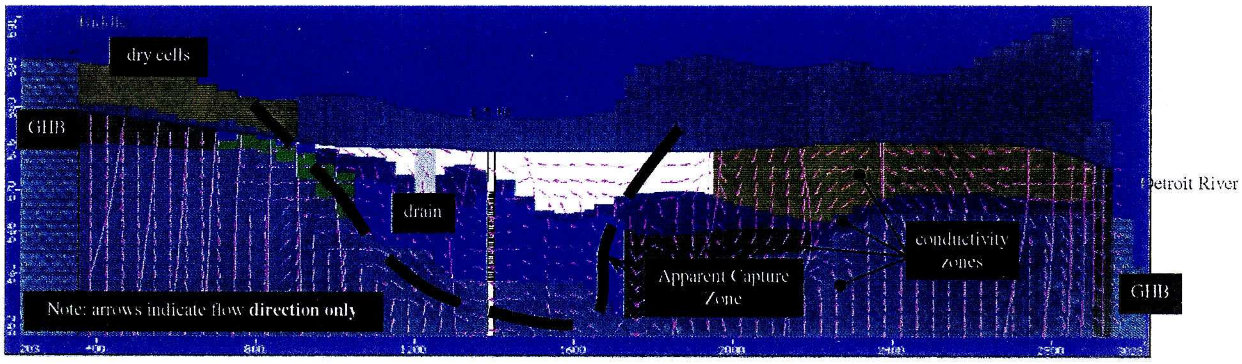

Figure 41. Flow for West-East Section through "B" Field Extraction Wells (Central)

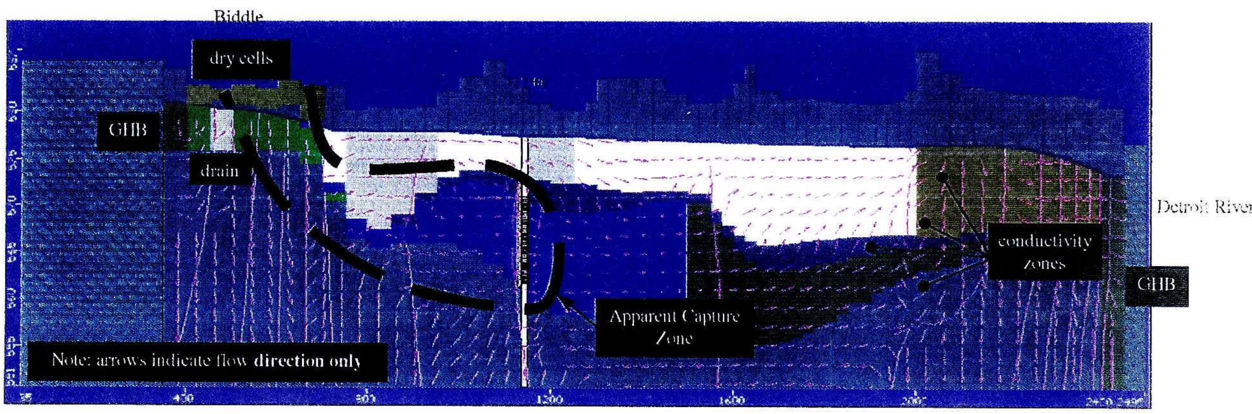

Figure 42. Flow for West-East Section through "C" Field Extraction Wells (North)

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7.2 Water Level Calibration Statistics

Water level calibration targets were calculated as the average of measured water levels in observation wells between July 1998 and April 2001. These values are shown on **Figure 43. Water Level Calibration Points**. Water level calibration data is tabulated in **Appendix C**, and is described in the following figures:

- **Figure 44. Calibration Plot – Water Levels in All Wells**
- **Figure 45. Calibration Plot – Water Levels in Fill**
- **Figure 46. Calibration Plot – Water Levels in Native Sand**
- **Figure 47. Calibration Plot – Water Levels in Mixed Units**
- **Figure 48. Calibration Residuals Histogram**
- **Figure 49. Areal Distribution of Calibration Residuals – Fill**
- **Figure 50. Areal Distribution of Calibration Residuals – Native Sand.**

The overall calibration to water levels shows a 5.1% normalized RMS residual. The mean residual is 0.06 ft, and the average absolute residual is 0.30 ft. Considering the highly heterogeneous nature of the fill at the site, these values are considered excellent. Further calibration is not warranted, since the uncertainty due to seasonal fluctuations (approximately 2 ft – see **Graph 2**) is greater than the RMS residual.

The residuals histogram (**Figure 48**) shows very little bias (a Gaussian distribution). The distribution of residuals in the fill unit (**Figure 49**) shows little or no areal bias. The largest residual in the fill is 1.17 ft. The distribution of residuals in the native sand unit (**Figure 50**) shows a slight East-West bias along a drain in the center of the site in the native sand, an artifact of the local drain boundary condition. This bias has been reduced in subsequent model revisions, producing a minor change in hydraulic head and flux distributions (average absolute residual = 0.25 ft). The largest residual in the native sand is 0.82 ft.

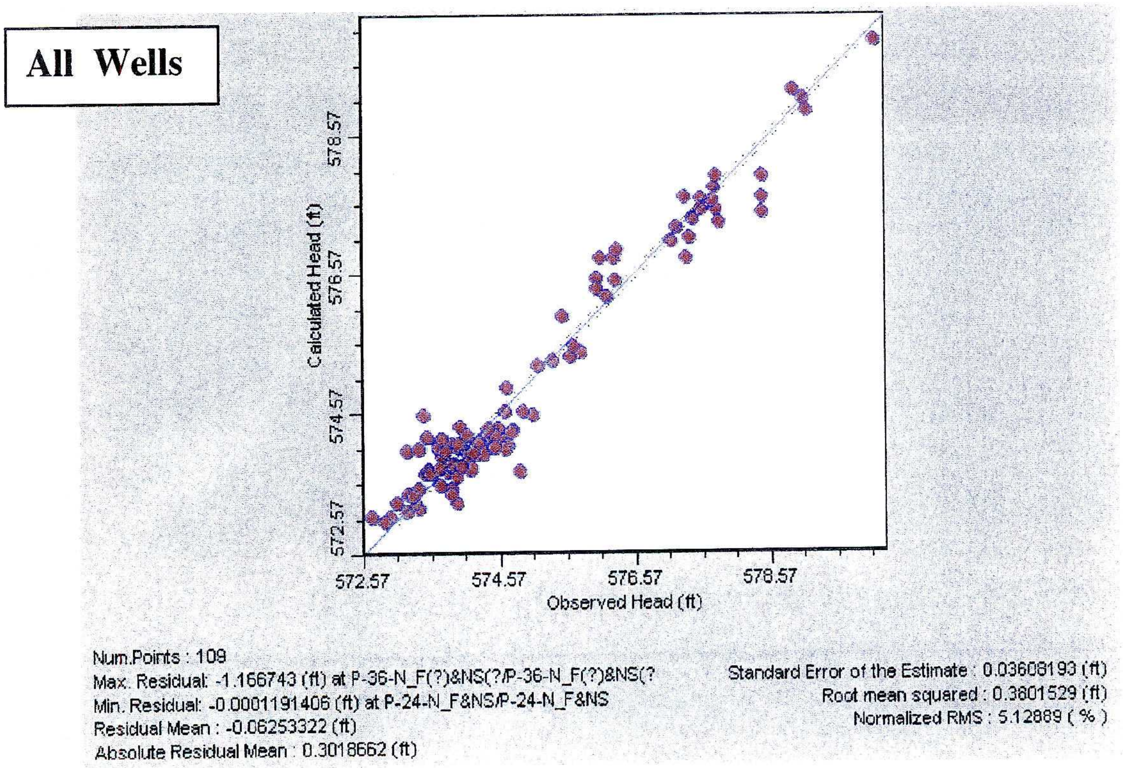


Figure 44. Calibration Plot – Water Levels in All Wells

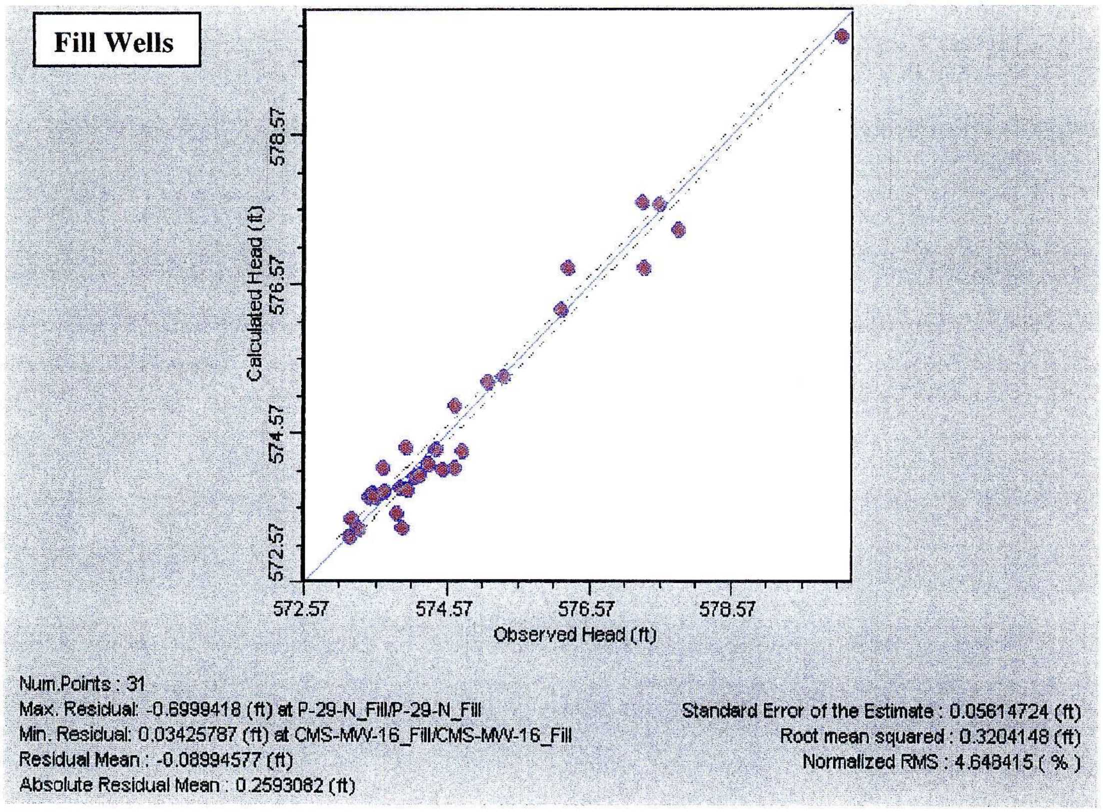


Figure 45. Calibration Plot – Water Levels in Fill

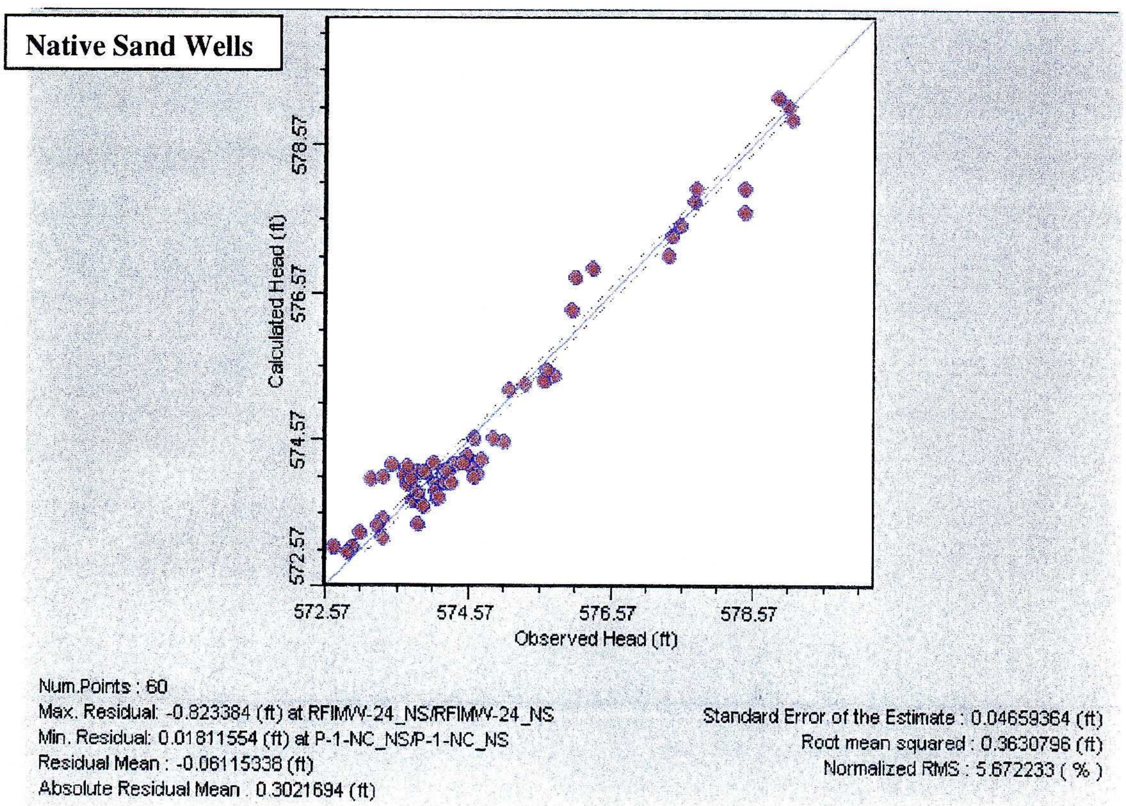


Figure 46. Calibration Plot – Water Levels in Native Sand

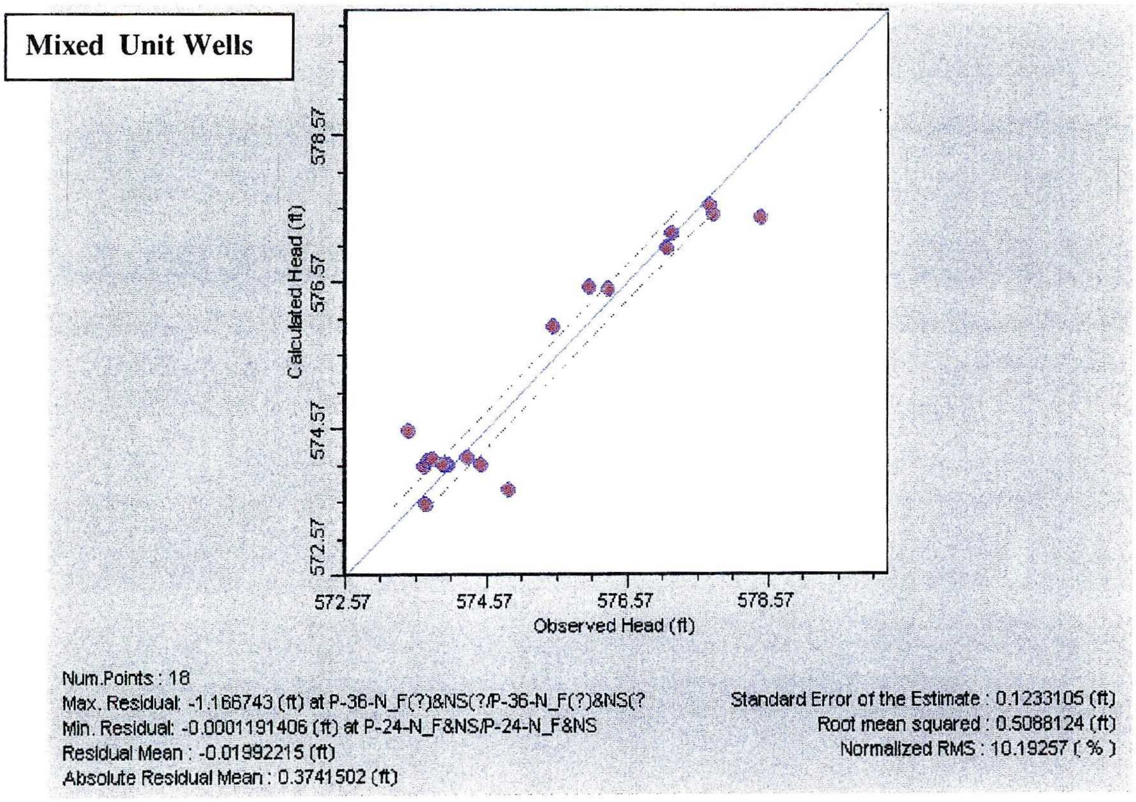


Figure 47. Calibration Plot – Water Levels in Mixed Units

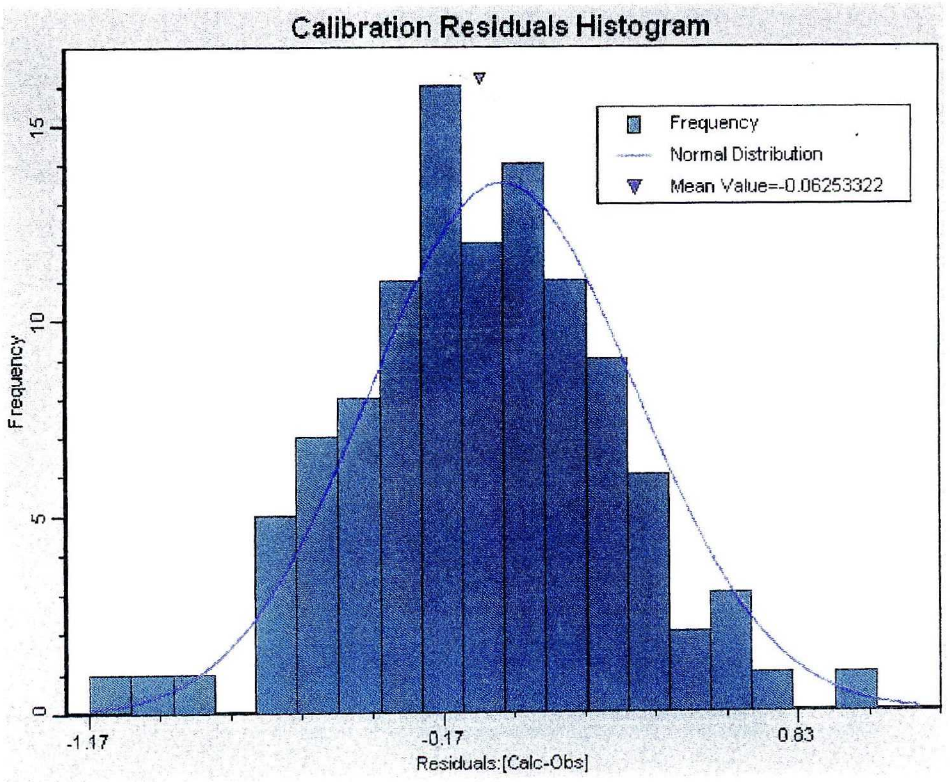


Figure 48. Calibration Residuals Histogram

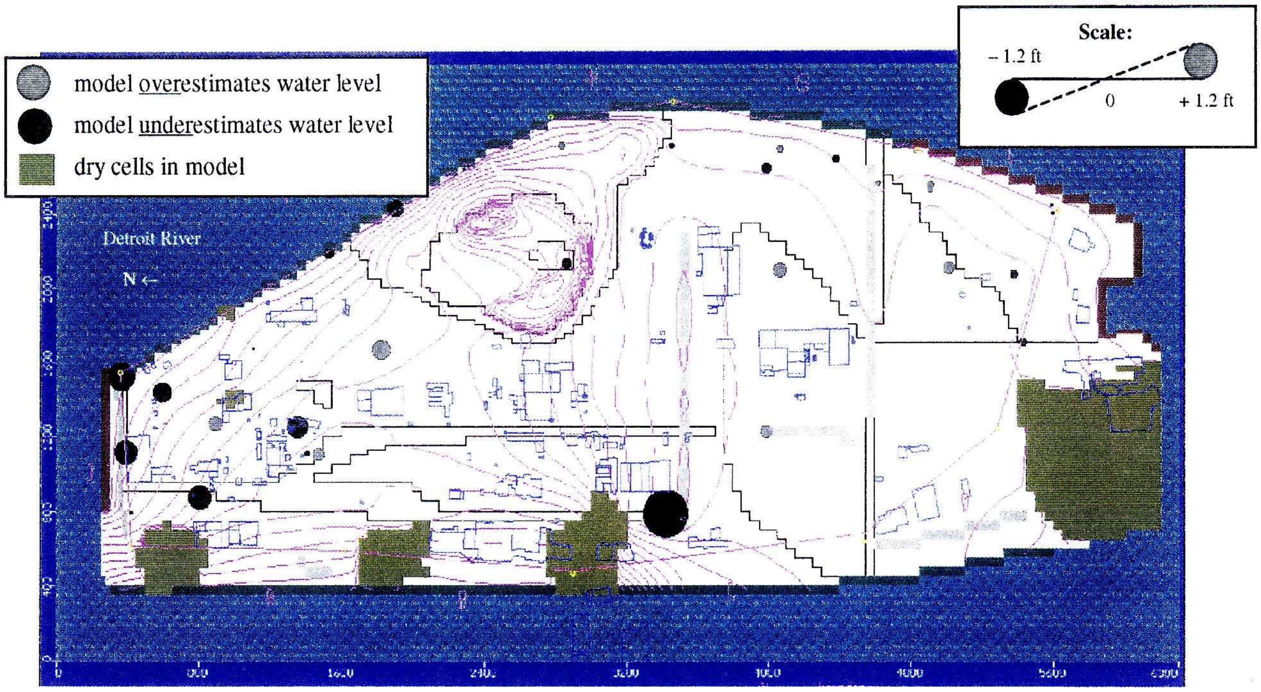


Figure 49. Areal Distribution of Calibration Residuals – Fill

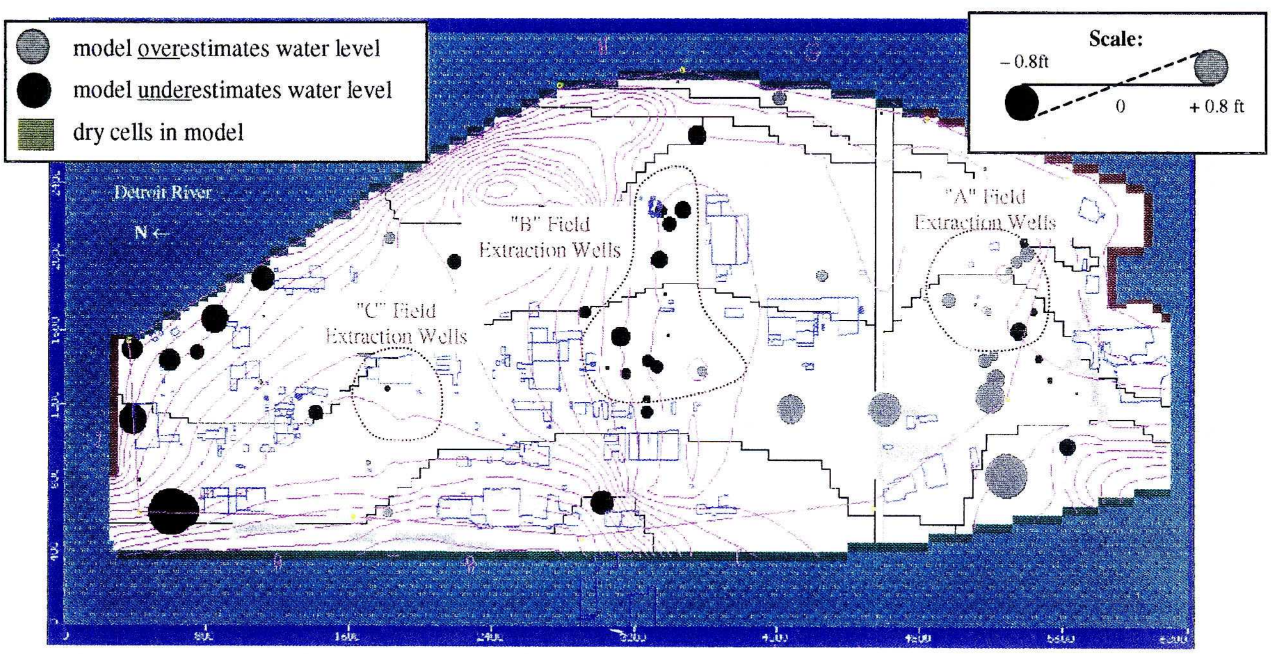


Figure 50. Areal Distribution of Calibration Residuals – Native Sand

7.3 Water Balance Calibration

Flow-through is important in assessing model uniqueness. In general, it is possible to construct calibrated models using different values of hydraulic conductivity. With higher values of hydraulic conductivity, the flow through the model will increase, so a good calibration depends on matching not only observed water levels in monitoring wells, but also on estimated flow through the model domain. Detailed water budgeting using the Zone Budget package within MODFLOW allows evaluation of model flow-through and estimation of flux rates through particular areas of interest at the site.

The basic variables in estimating flux through a boundary are conductivity (K), hydraulic gradient (i) and flow area (A), which depends on saturated thickness (b_{sat}).

$$Q = K \cdot i \cdot A$$

where:
- Q = boundary flux estimate (ft^3/d)
- K = saturated hydraulic conductivity of geologic unit (ft/d) – see Section 6.5 and **Appendix B**
- i = hydraulic gradient (slope of piezometric surface) in direction perpendicular to flow area (ft/ft) – from February 2002 data – see **Appendix D**
- A = cross-sectional area of flow (ft^2)
  = saturated thickness of geologic unit (ft) · length of boundary segment (ft).

A detailed derivation of flux calibration targets is contained in **Appendix D**. This is essentially an update of the 1984 calculation by SSPA (see Section 3.14), using data from the February 2002 water level monitoring (37 additional boundary points) and additional hydraulic conductivity data collected during the RFI and CMS investigations to account for current site conditions. The calibration target for each boundary segment was calculated as the geometric mean of an upper bound flux estimate and a lower bound flux estimate. As hydraulic conductivity is observed to vary by orders of magnitude over small distances, precise estimates of flux are not possible with this methodology, and the expected range of flux is correspondingly wide.

Model water balance was evaluated using the flow through 10 segments (A through J), which encompass the site. Overall model mass balance (in – out) was excellent (<0.15% discrepancy for each segment, and <0.03% globally), indicating that the model successfully converges to steady-state conditions. The model correctly predicts net flow direction for each segment, for both Fill and Native Sand units.

Detailed flux calibration statistics are contained in **Appendix D**. In **Figure 51** (below), the flux calibration statistics are plotted by summing the estimated flux through both the native sand and fill units for each of the boundary segments. The combined flux is within the estimated bounds for each segment.

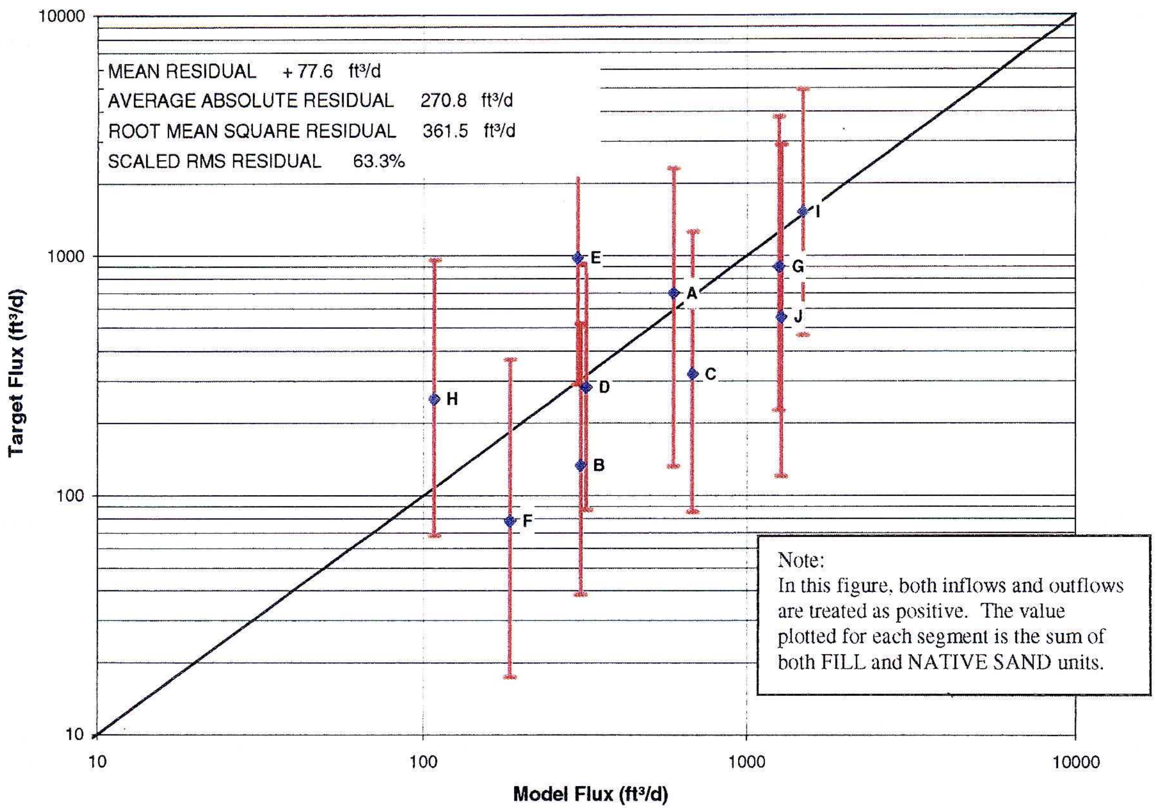


Figure 51. Calibration Plot - Boundary Flux

The boundary flux calibration is assessed in more detail in **Figure 52** and **Figure 53** (below), which consider the Fill and Native Sand units separately, using the same 10 boundary segments.

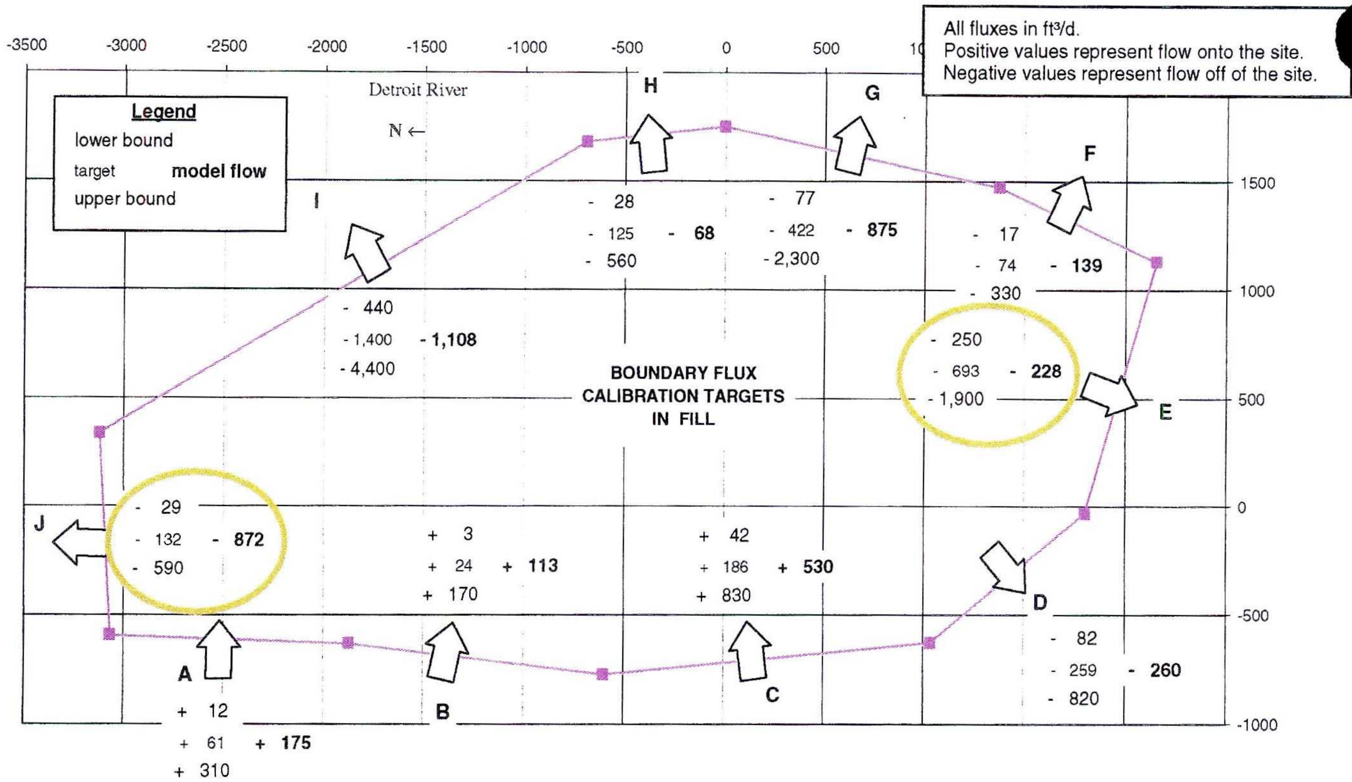


Figure 52. Boundary Flux Calibration– Fill

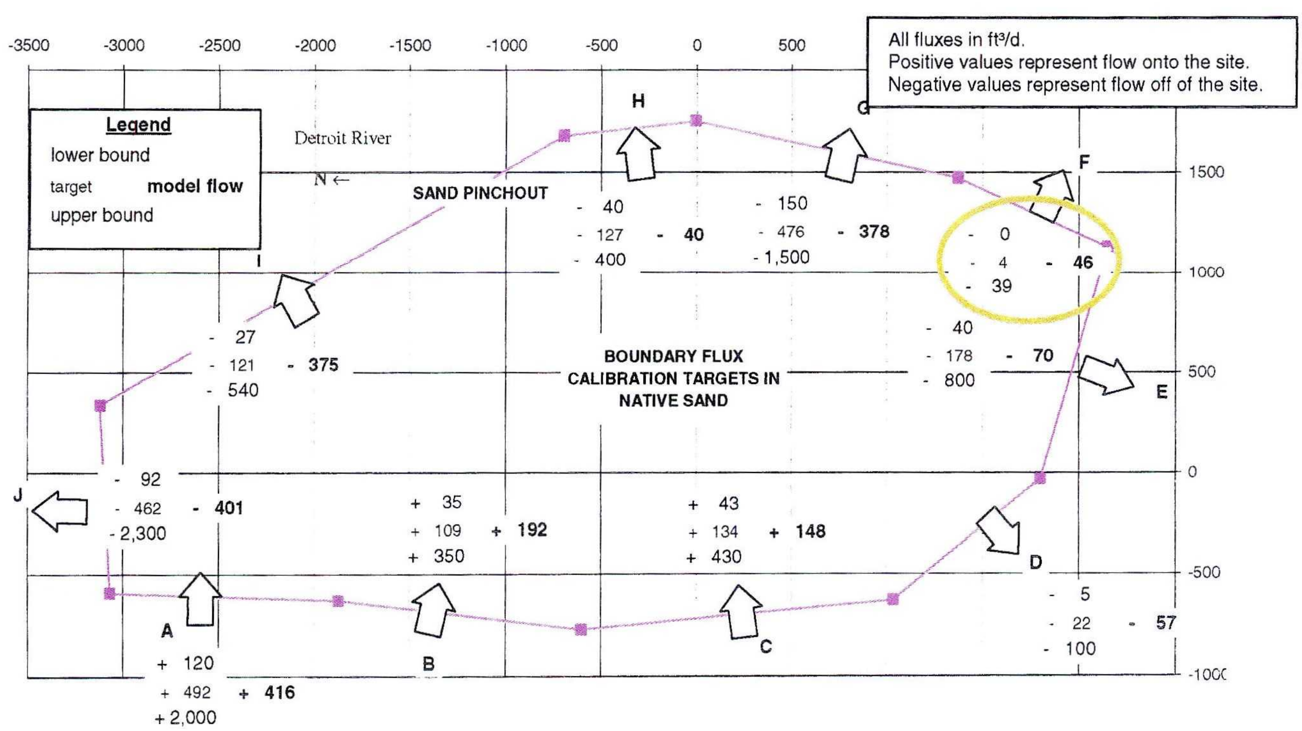


Figure 53. Boundary Flux Calibration – Native Sand

Recognizing that flux depends on hydraulic conductivity, which is highly variable, **Figure 52** and **Figure 53** include an estimated upper and lower bound for the flux estimates. As noted on these figures, the boundary flux estimate predicted in the model is outside the expected range for three out of the 20 boundary segments (circled in yellow). Only two of these differences from the calibration targets are considered significant – south to Mulberry Street, where the model-estimated flux is lower than expected, and north to Perry Place, where it is greater than expected. The estimated flux through segment F in the Native Sand is statistically outside the expected range, but is not of practical significance.

7.4 Predicted Flows

The flows predicted by the model are perhaps its most important outputs. It is important to recognize that there is no way to directly measure the groundwater discharge volume at the site, and as all estimates depend on highly heterogeneous factors such as transmissivity, the range of uncertainty is relatively high. The calibrated groundwater flow model is expected to provide the most realistic and reliable estimates for groundwater flows at the site.

Table 6 below outlines how precipitation is partitioned at the site. The data in **Table 6** are a combination of the results from the USEPA HELP model (scaled to account for the site as 70% permeable and 30% impermeable cover, by area), and the MODLOW groundwater flow model, within the 231 acre footprint of the site boundary. These predicted values may be compared with the values in **Table 3** from 1984 (non-pumping conditions), and with **Graph D3** in **Appendix D** for the model domain as a whole (290 acres).

Table 6. Precipitation Partitioning for Site

Inputs to Site	Flow Rate (ft^3/d)	Estimated Uncertainty	% Total	Comment
Direct precipitation	70,000	± 20%	97 %	HELP model
Surface water run-on	?			not expected to be significant
Groundwater (diffuse flow from Biddle Av.)	**1,900**	± 50%	3 %	see **Graph D3**
Total measured and estimated Inputs	72,000		100 %	
Discharges from Site				
Evapotranspiration	33,000	± 50%	48 %	HELP model – silty clay / clay
Surface water run-off	10,000	± 50%	14 %	HELP model – silty clay / clay
Interception by storm drainage system	21,000	± 20%	30 %	paved or built portions of site
Groundwater (diffuse flow east to Detroit R.)	**3,100**	± 50%	5 %	see **Graph D3**
Groundwater (diffuse flow north to Perry Pl.)	**1,000**	± 50%	1.5%	see **Graph D3**
Groundwater (diffuse flow south to Mulberry St.)	**400**	± 50%	0.5%	see **Graph D3**
Groundwater (diffuse flow west to Biddle Av.)	**550**	± 50%	0.8%	see **Graph D3**
Total measured and estimated Discharges	68,600		100 %	
absolute % discrepancy in water balance	4.3%			
Groundwater Recharge	6,250	± 50%	9 %	Direct precipitation + Net run-on – Evapotranspiration – Interception

7.5 Parameter Optimization and Sensitivity Analysis

Sensitivity analyses cover important hydrogeologic parameters, principally recharge and hydraulic conductivity. These statistical measures of model calibration were conducted using WinPEST optimization software to generate standard sensitivity plots.

WinPEST works by systematically varying the values of input parameters to minimize an objective function, which in this case is the weighted sum of squared residuals for head and flux observations. Mathematically,

$$\textit{minimize } \phi = \phi_H + \phi_Q = \Sigma\, w_i^{\,2} \cdot (H_{model} - H_{target})_i^{\,2} + \Sigma\, w_j^{\,2} \cdot (Q_{model} - Q_{target})_j^{\,2}$$

where:
- ϕ = the overall calibration objective function
- ϕ_H = the calibration objective function for water levels (H)
- ϕ_Q = the calibration objective function for flows (Q)
- w_i = the weight associated with water level observation i (i = 1 to number of water level observations)
- w_j = the weight associated with flow observation j (j = 1 to number of flow observations)

The values of H_{target} are the average of measured water levels at observation wells from four monitoring events between July 1998 and April 2001. There were 110 wells included in the objective function. These wells, and their associated water level targets, are shown on **Figure 43. Water Level Calibration Points**. A weight (w_i) of 1.0 was used for all wells screened in the Fill unit or Native Sand unit, and a reduced weighting of 0.5 was used for wells screened in mixed or uncertain units.

Values of Q_{target} are derived from water levels measured during February 2002. Details of the calculations are contained in **Appendix D**. There were 20 flux values included in the objective function, corresponding to the ten boundaries (A through J) and two units (Fill and Native Sand). The boundaries, and their associated flux targets, are shown on **Figure 52** and **Figure 53**. All flux targets were assigned a weight (w_j) of 0.003, which accounts for the different units of measure (H in ft, Q in ft^3/d).

Calibration was effective in reducing the water level component of the objective function. Less progress was made in reducing the flow component. See **Table 7** below for information on the relative reductions in the different components of the objective function.

Table 7. Optimization with WinPEST

	starting values		final values	
ϕ_Q	18.7	23%	15.1	53%
$\phi_{H\ NS}$	41.9	51%	8.0	28%
$\phi_{H\ Fill}$	18.7	23%	4.1	14%
$\phi_{H\ Mixed}$	3.6	4%	1.2	4%
ϕ (obj. fn)	82.8	100%	28.3	100%

Parameter correlation is examined in **Figure 54. Matrix of Parameter Correlation.**

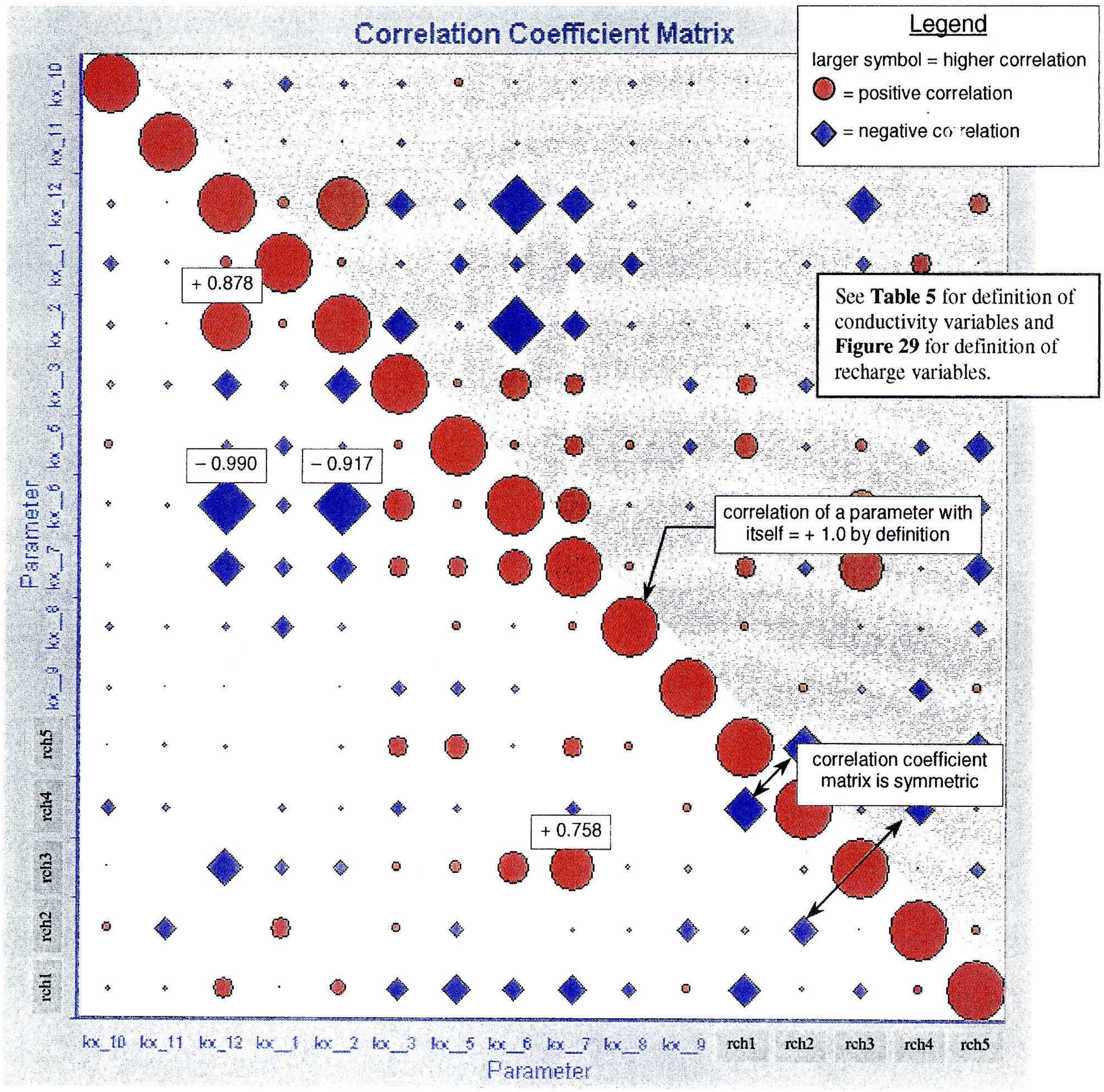


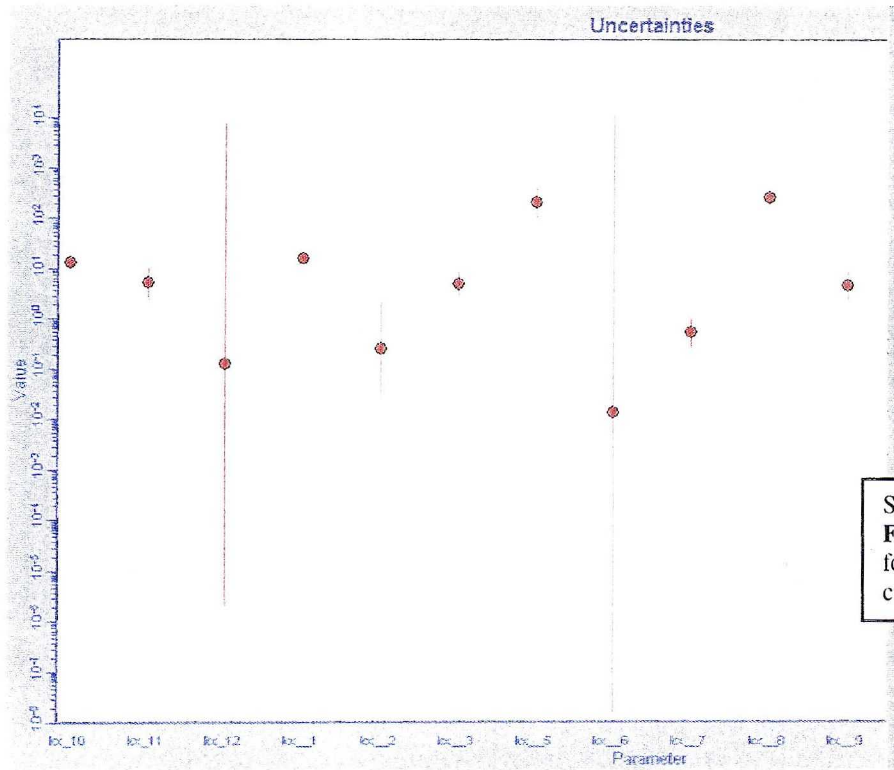
Figure 54. Matrix of Parameter Correlation

Where high positive correlation exists between two model parameters, these parameters may be adjusted in the same direction (i.e. both increased or both decreased) without affecting the model calibration. Negative correlation implies that the relation exists in the opposite sense, i.e., an increase in one can be combined with a decrease in the other without sacrificing model calibration. Correlation between parameters increases the uncertainty in the "true" value of either parameter. This effect gives rise to the non-uniqueness in groundwater models.

As shown, there is a high positive correlation (r = + 0.88) between the hydraulic conductivity of the upper DBO (Kx12) and that of the Peat (Kx2). The conductivity of the upper DBO is also highly, but negatively, correlated to the conductivity of the adjoining DBO (Kx6) (r = – 0.99). Significant correlations also exist between the conductivities of Peat and DBO in the model (r = – 0.91) and between the conductivity of lower DBO and low recharge areas (rch3) (r = + 0.76). This means, for example, that an ***increase*** in the model value for the conductivity of the fill in the lower DBO area, together with a corresponding ***increase*** in the model value for low recharge, would yield a similar model result.

The correlations that exist between parameters in the model are understandable and reasonable. The incorporation of flow estimates in addition to water levels has greatly reduced parameter correlation.

The correlations that exist for Peat (Kx2), DBO (Kx6), and upper DBO (Kx12) directly influence our confidence in their value. As shown in **Figure 55**, these parameters have larger uncertainties than do others. The generally narrow confidence bands on other parameters indicate that correlation is not a serious problem – the use of combined flow and water level calibration improves model uniqueness significantly.



See **Table 6** and **Figures 30** to **33** for definition of conductivity zones.

Figure 55. Approximate 95% Confidence Limits on Model Hydraulic Conductivities

Model parameter sensitivity is important to assessing the confidence we have in model results. Sensitive parameters affect calibration statistics significantly, while insensitive parameters have little effect on calibration statistics. Thus, the process of model calibration should continually refine and improve the values of sensitive parameters, while the values of insensitive parameters are typically not improved during calibration.

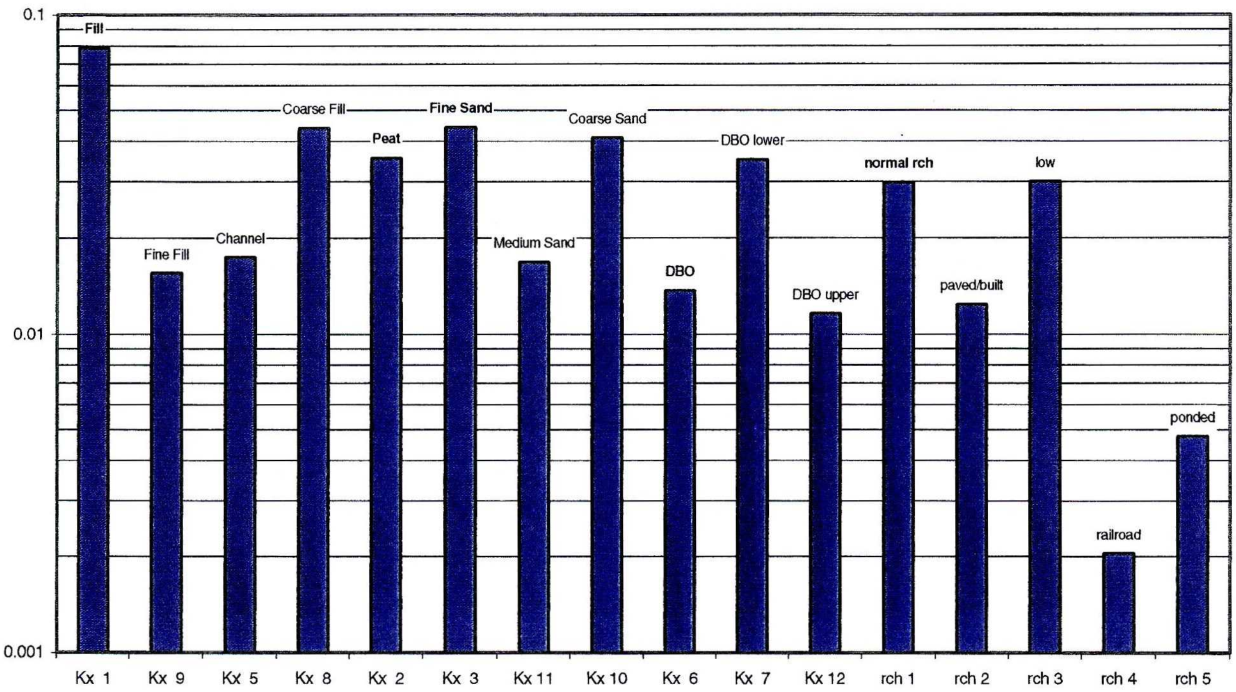


Figure 56. Parameter Sensitivity

As shown in **Figure 56** above, the hydraulic conductivity of the Fill unit is the most sensitive parameter in the model, and areas of the highest recharge (rch4 = 7.1 in/year) the least sensitive. It is worth noting that only 2 of the 17 variable parameters have sensitivities below 0.01. This balanced result indicates that the numerical model is well constrained and augments confidence in the calibration. No one parameter dominates and all play a significant role in the overall flow regime at the site.

7.6 Predictive Simulations

Simulation scenarios have not been defined at this time. Possible analyses include capture zones for extraction wells, and three-dimensional visualizations, such as shown in **Figure 57. Hypothetical Visualization of Remediation Modeling**.

8.0 Summary

Groundwater modeling of the entire BASF North Works Facility in Wyandotte, Michigan is being undertaken to enhance the understanding of the groundwater flow system and to identify alternative corrective measures as part of the RCRA process. The model developed allows BASF to evaluate the capacity of existing and proposed hydraulic control systems at the site.

To develop this site-scale groundwater flow model, existing data sources regarding regional geology, site stratigraphy, head observation wells, pumping wells, river level, etc. were utilized. This study builds upon the previous Current Conditions Report and RCRA Facilities Investigation completed at the site. This information has been integrated into a site database using GIS for a comprehensive analysis of the available hydrogeologic data.

The current report presents the analyses that have been developed to date and the approach taken to construct and calibrate the numerical groundwater flow model. The model represents the full three-dimensional groundwater flow system and extends into the underlying Lacustrine Clay. Incorporation of flow estimates in the calibration proved key to developing a realistic model. The calibrated flow model does an excellent job of predicting the fundamental aspects of groundwater flow, namely, water level, flow direction, and flow volume.

The site-scale model developed will provide the basis for comprehensive analysis of hydraulic options for corrective measures. The model should be viewed as a tool to be updated as new data, or the understanding of the site, changes. Based on the solid understanding of the groundwater flow regime at the site, solid and stable model construction and calibration, we see no obstacles toward proceeding with predictive simulations of remedial options. WHI is confident that the calibrated three-dimensional numerical groundwater flow model is an excellent tool for evaluating alternative corrective measures at the BASF Wyandotte North Works Facility.

9.0 References

Harbaugh, Arlen W.; Banta, Edward R.; Hill, Mary C.; and McDonald, Michael G., 2000, MODFLOW-2000, The U.s. Geological Survey Modular Ground-Water Model, U.S. Geological Survey Open-File Report 00-92, 121 pp

Holtschlag, D.J., 1996, *A Generalized Estimate of Ground-Water-Recharge Rates in the Lower Peninsula of Michigan*: U.S. Geological Survey Open-File Report 96-593, 37 pp.

Michigan Department of Natural Resources and the Ontario Ministry of the Environment 1991, *Detroit River Remedial Action Plan.*

Ostaszewski, A. 1997. *Results of the Trenton Channel Project Sediment Surveys 1993-1996.* Michigan Department of Environmental Quality, SWQD, Lansing, MI. 105 pp.

Parsons Engineering Science, Inc., 1998. *Update of 1994 RCRA Facility Investigation Report of Current Conditions.*

Parsons Engineering Science, Inc., *RCRA Corrective Measures Study, Field Program Report, for the BASF North Works Facility, Wyandotte, Michigan*, USEPA ID Number MID 064197742, March 2000

QST Environmental (formerly Environmental Science & Engineering, Inc.), *Phase I RCRA Facility Investigation Report for BASF-Wyandotte Facility*, 26 February 1999

S.S. Papadopulos & Associates, Inc., 1984, *Rate and Direction of Groundwater flow at the North Works, BASF Wyandotte Corporation, Wyandotte, Michigan, Volume I: Main Report* and *Volume II: Appendices.*

S.S. Papadopulos & Associates, Inc., 1985, *Preliminary Evaluation of Extraction Well Systems, BASF Wyandotte Corporation North Works*, Wyandotte, Michigan

S.S. Papadopulos & Associates, Inc., 1991, *Evaluation of Extraction Well Systems, BASF Corporation North Works, Wyandotte, Michigan.*

United States Environmental Protection Agency, et. al., 1988, *Upper Great Lakes Connecting Channels Study, Volume II*, 626 p.

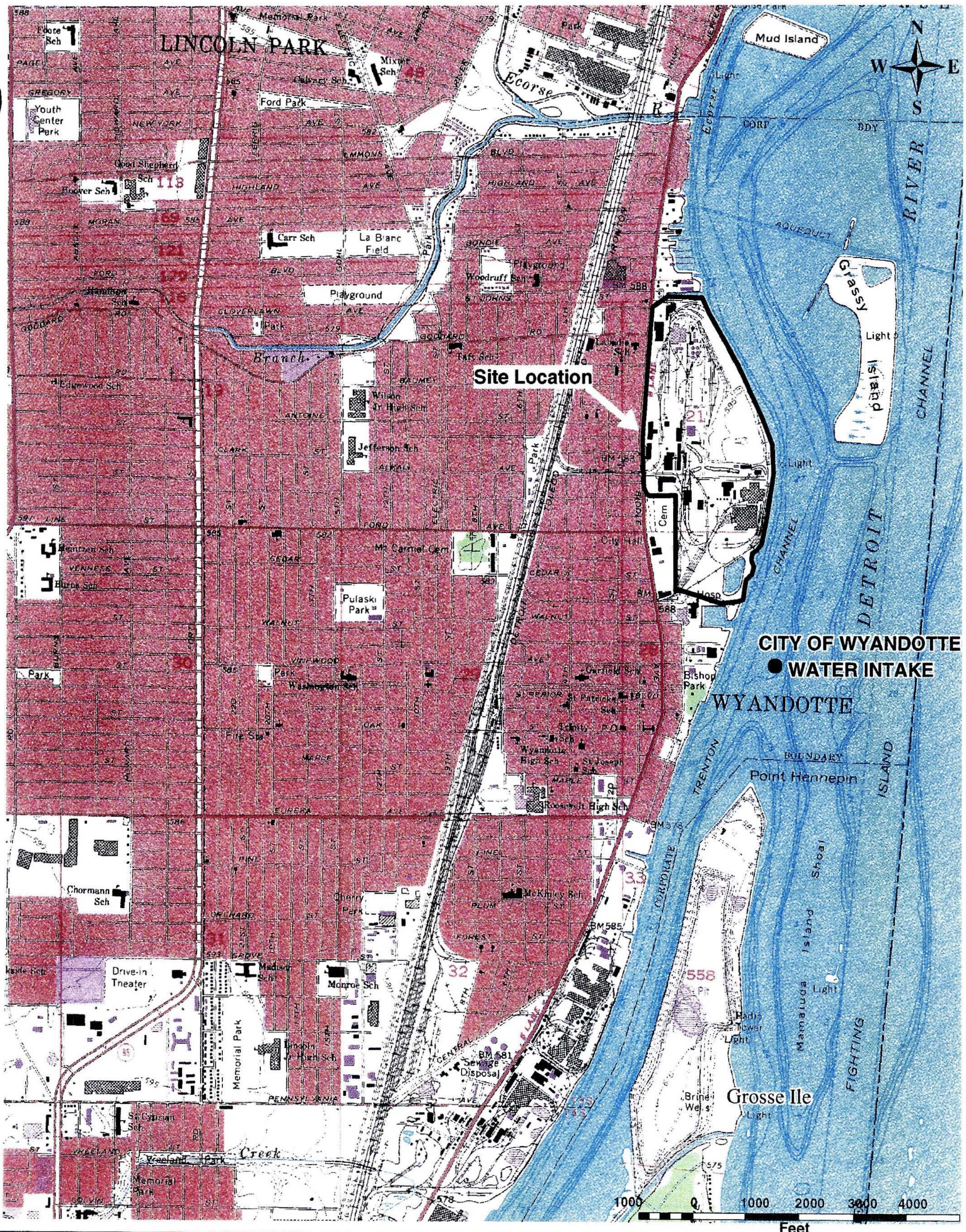
Waterloo Hydrogeologic, Inc., May 2002, *Field Program Report.*

Woodward-Clyde Consultants, 1994. *RCRA Facility Investigation Report of Current Conditions.*

File: D:\projects\BASF-Wyandotte\docs\calibration_report_draft_final.doc

Appendix A

Full Page Figures



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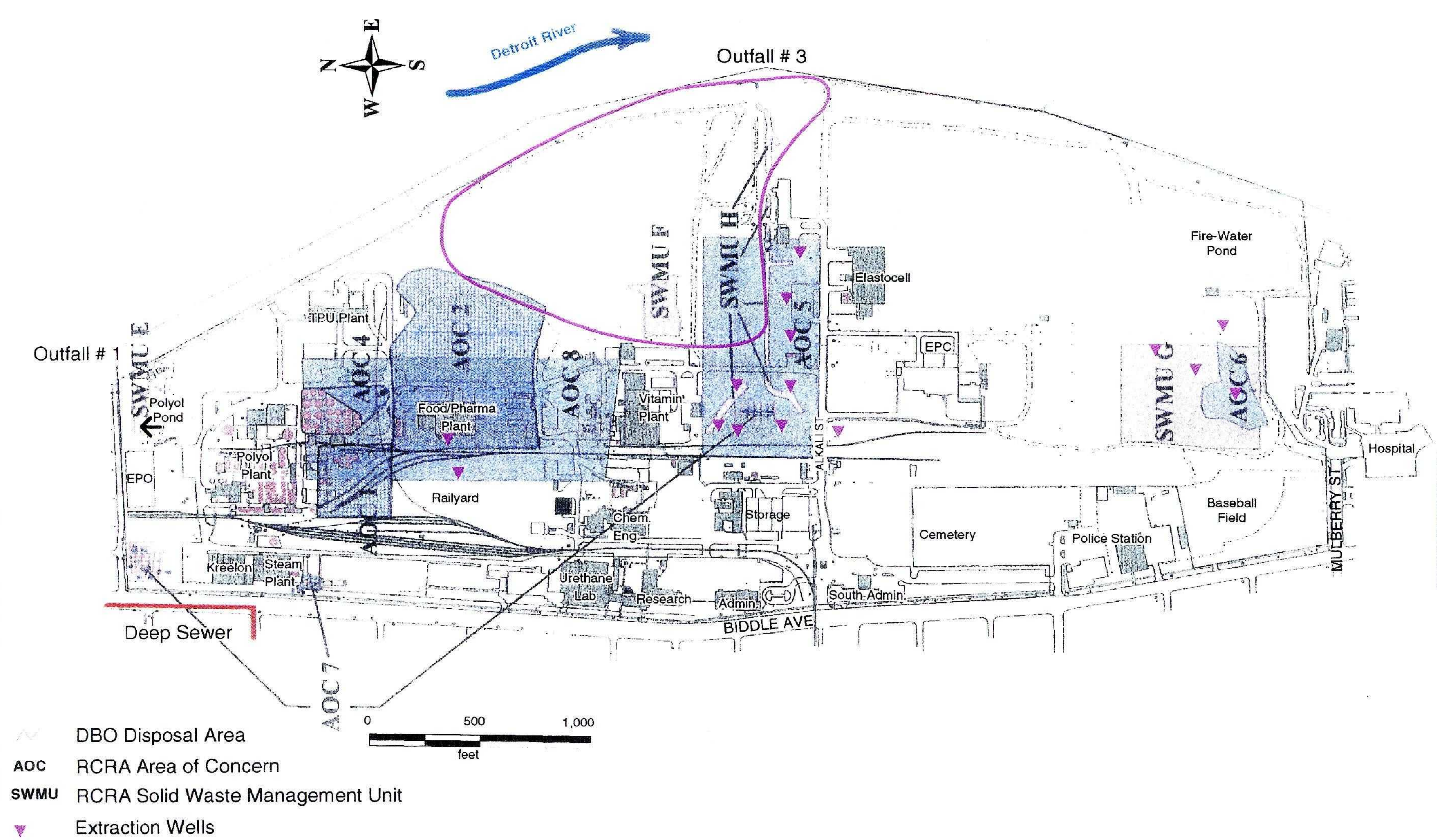
Site Location Map

BASF-Wyandotte North Works

Figure 1

CMS Groundwater Modeling

June 2002



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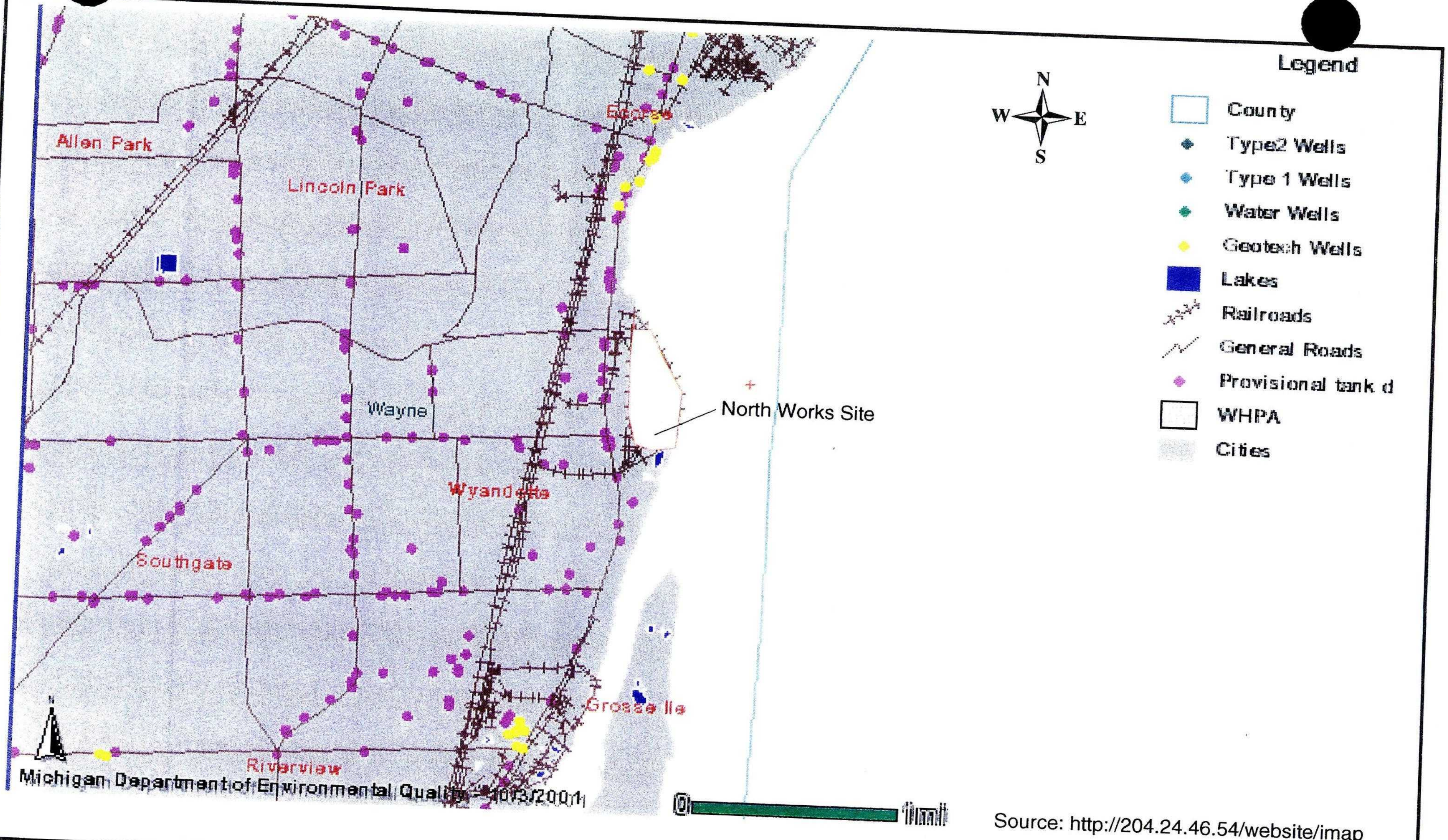
Existing Site Layout

BASF-Wyandotte North Works

Figure 2

CMS Groundwater Modeling

June 2002



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Surrounding Subsurface Information

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Figure 3

CMS Groundwater Modeling

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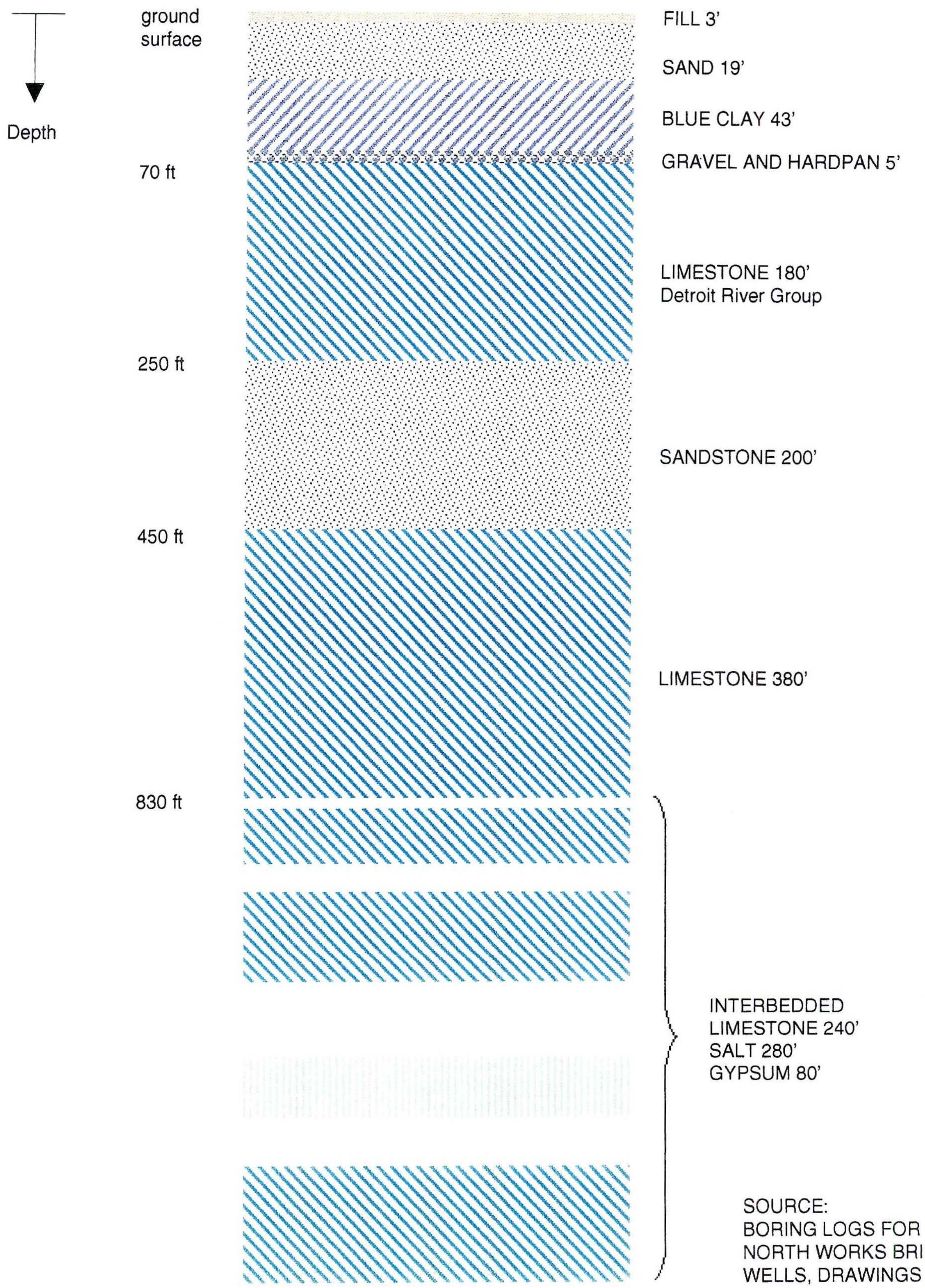

SOURCE:
BORING LOGS FOR NORTH WORKS BRINE WELLS, DRAWINGS NO. 14590 (1947) & 16532 (1951)

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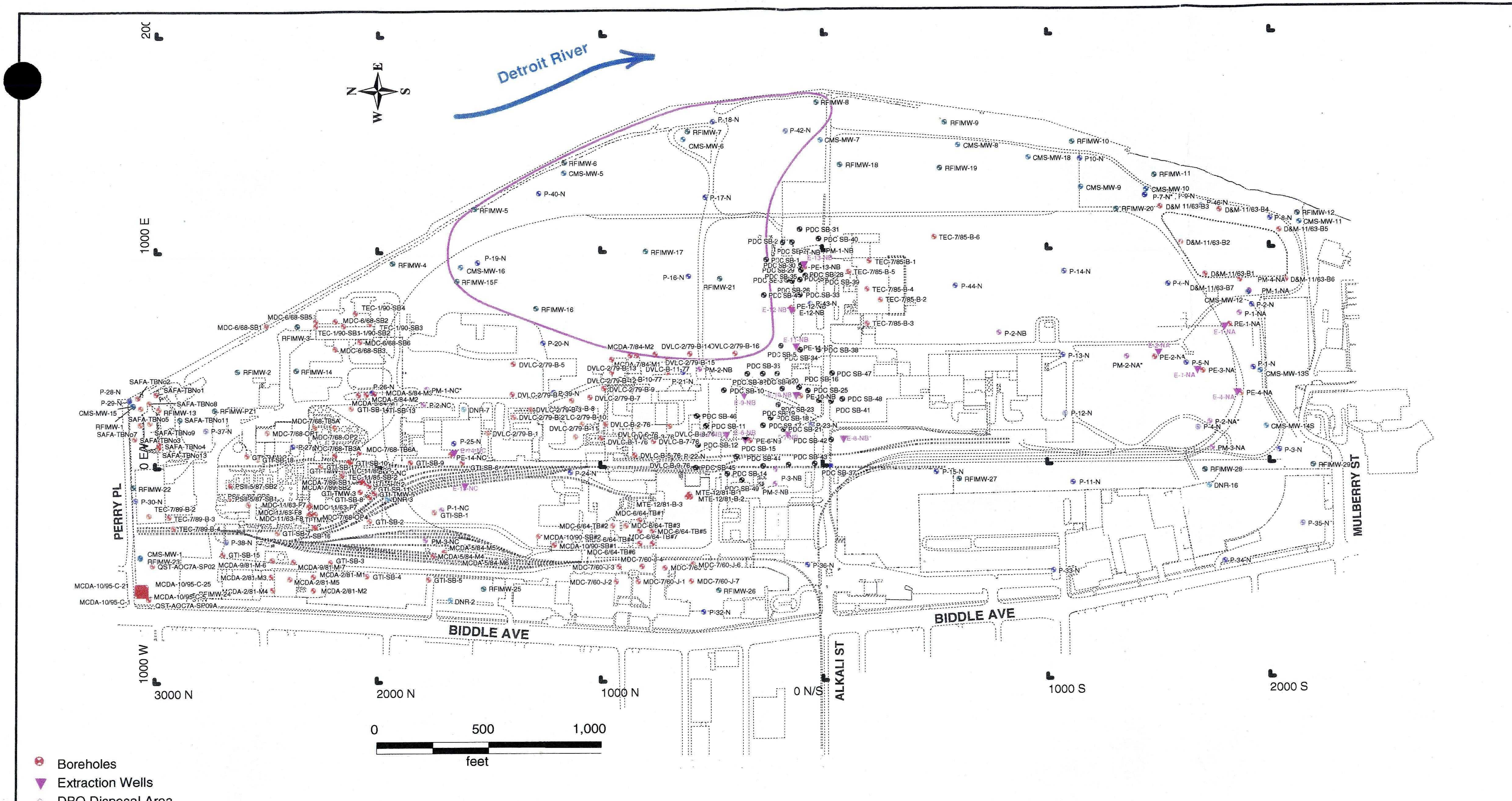

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Environmental and Geotechnical Borehole Locations

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Figure 5

CMS Groundwater Modeling

June 2002

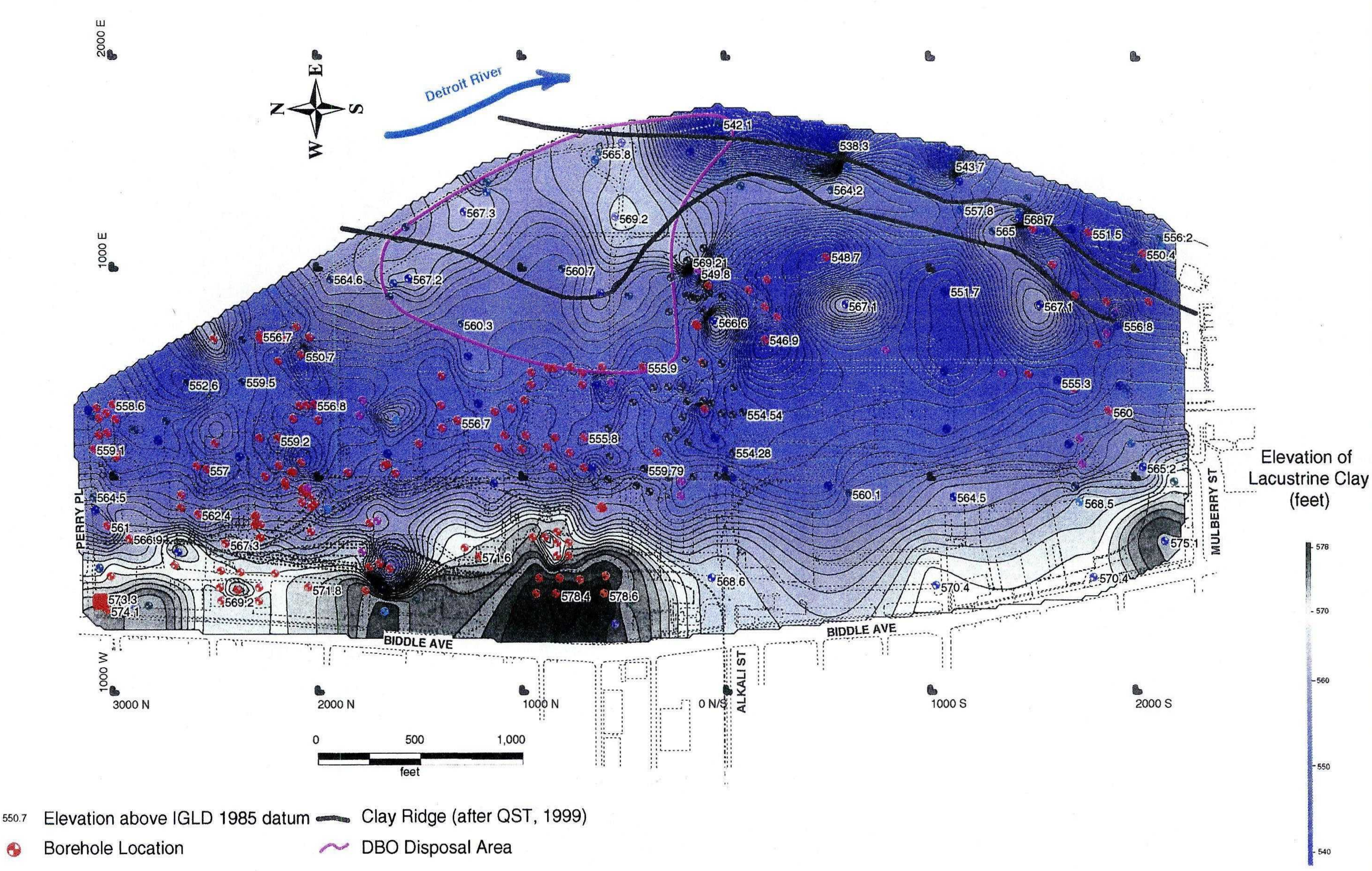

Figure 6a) Current Interpretation of Elevation of Top of Lacustrine Clay Surface.

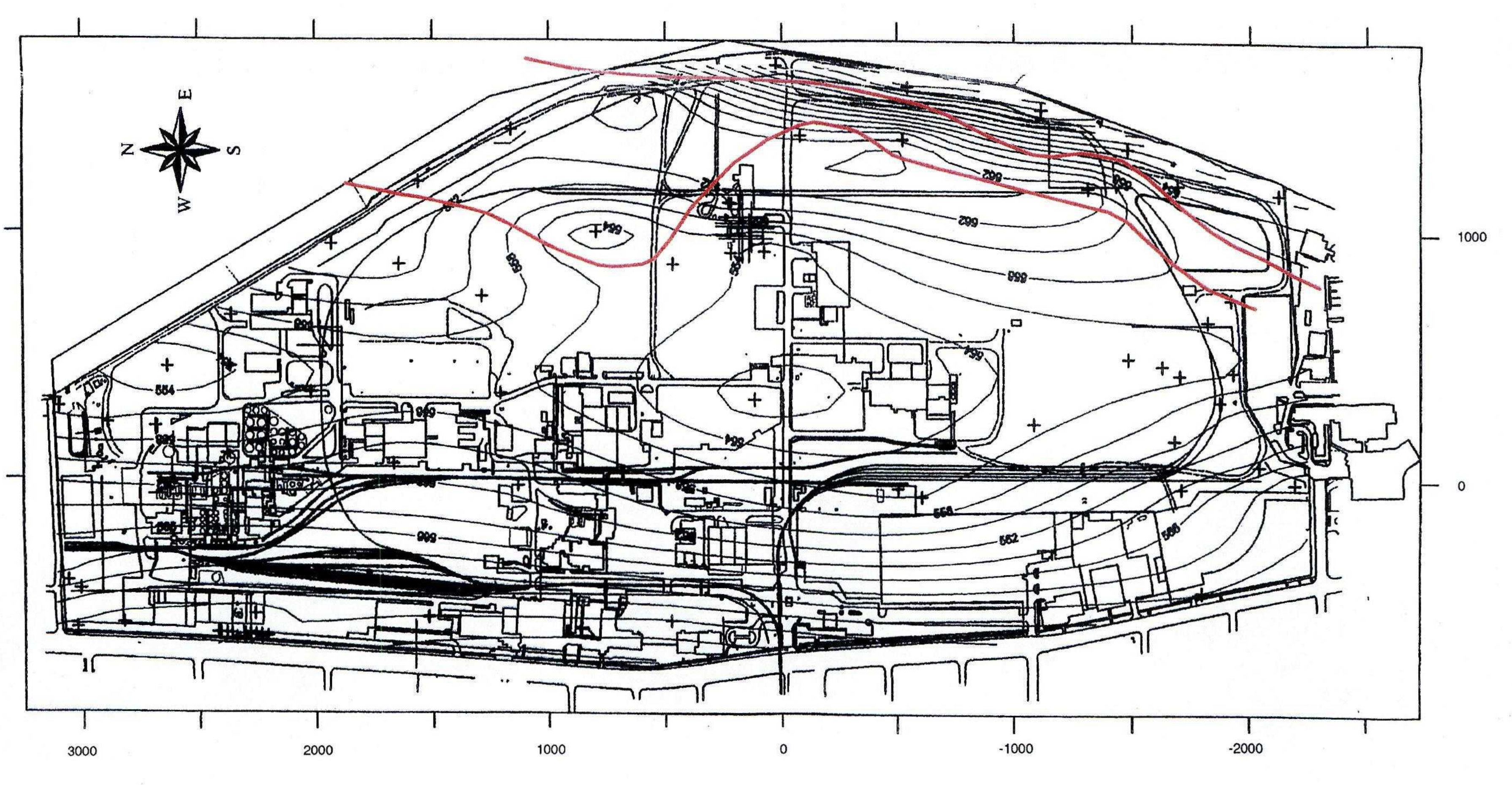

Figure 6b) Previous Interpretation of Elevation of Top of Lacustrine Clay Unit. Modified RFI Figure 7-9 (QST, 1999).

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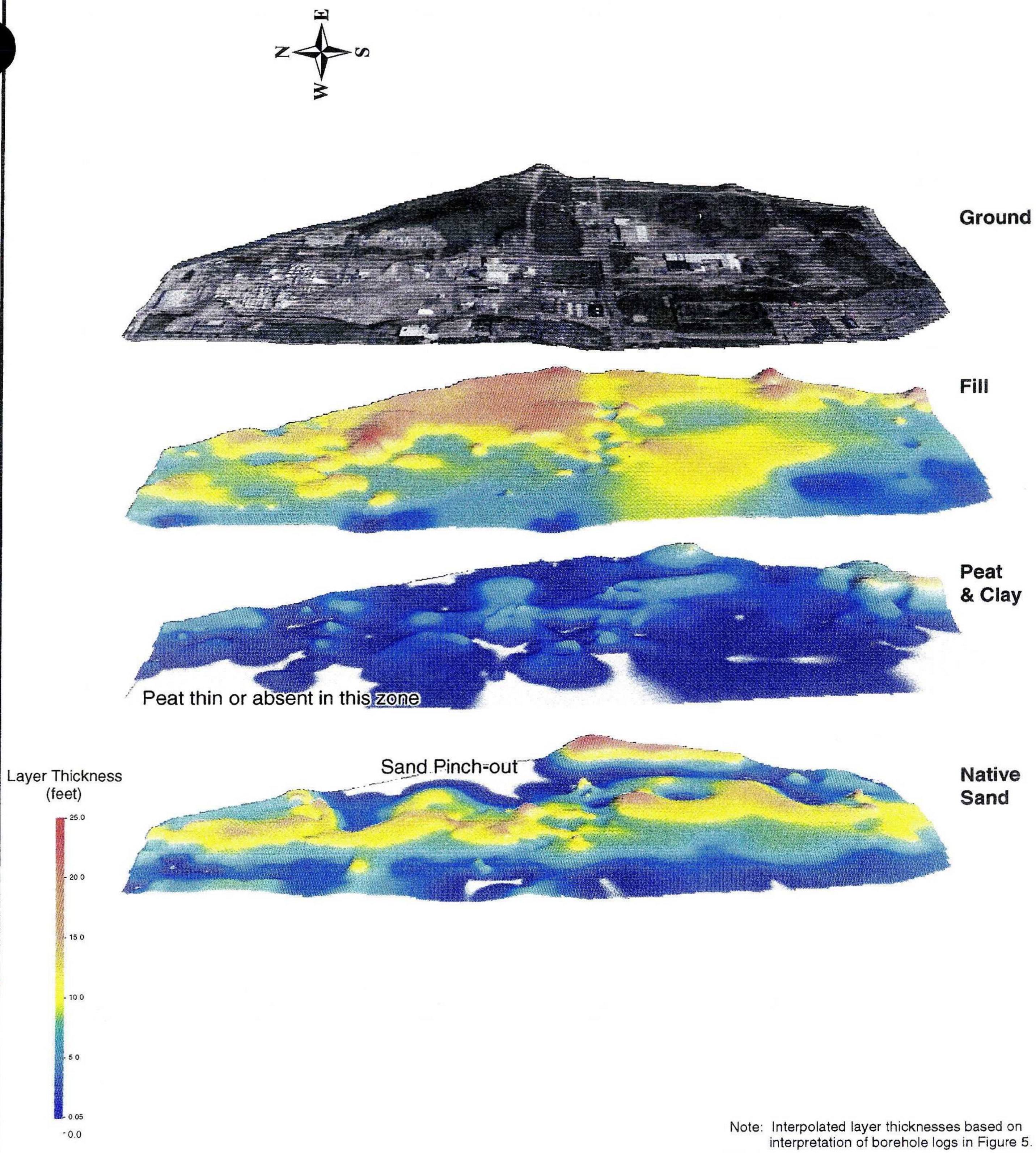

Note: Interpolated layer thicknesses based on interpretation of borehole logs in Figure 5.

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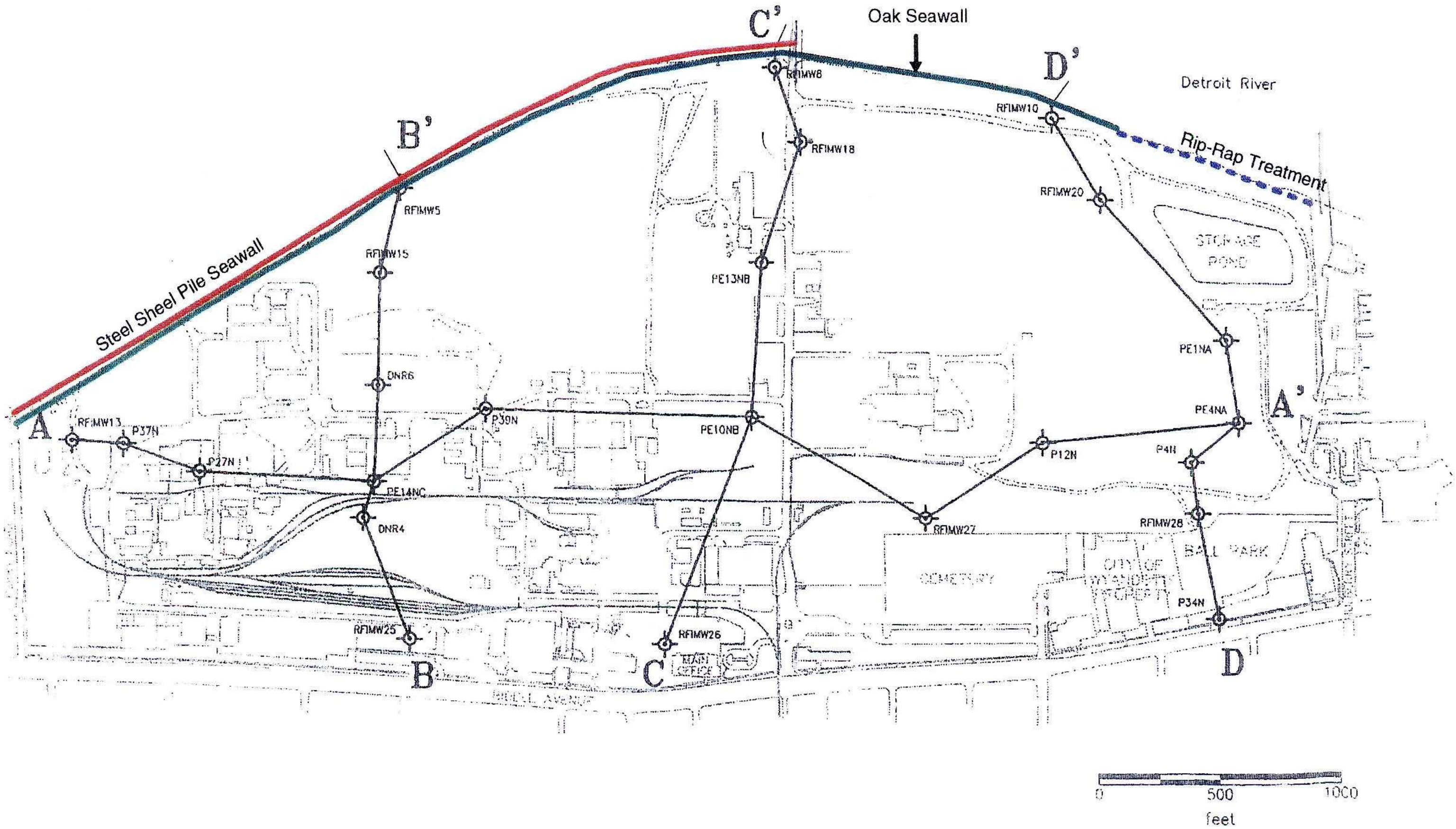
Layer Isopachs

BASF-Wyandotte North Works

Figure 7

CMS Groundwater Modeling

June 2002



Borehole Location

Note: After QST (1999)

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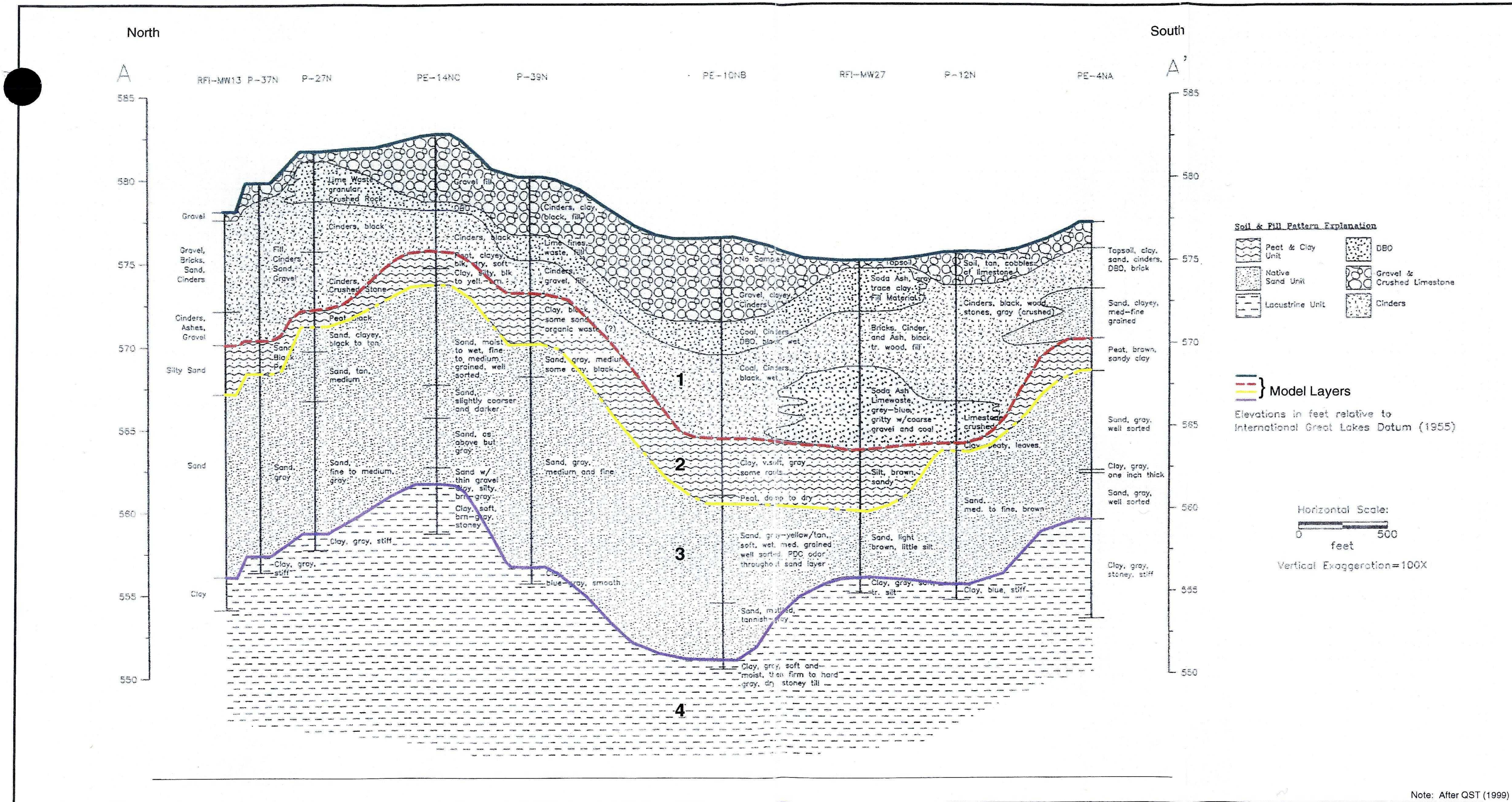
Hydrostratigraphic Cross-Section Locations

BASF-Wyandotte North Works

Figure 8

CMS Groundwater Modeling

June 2002



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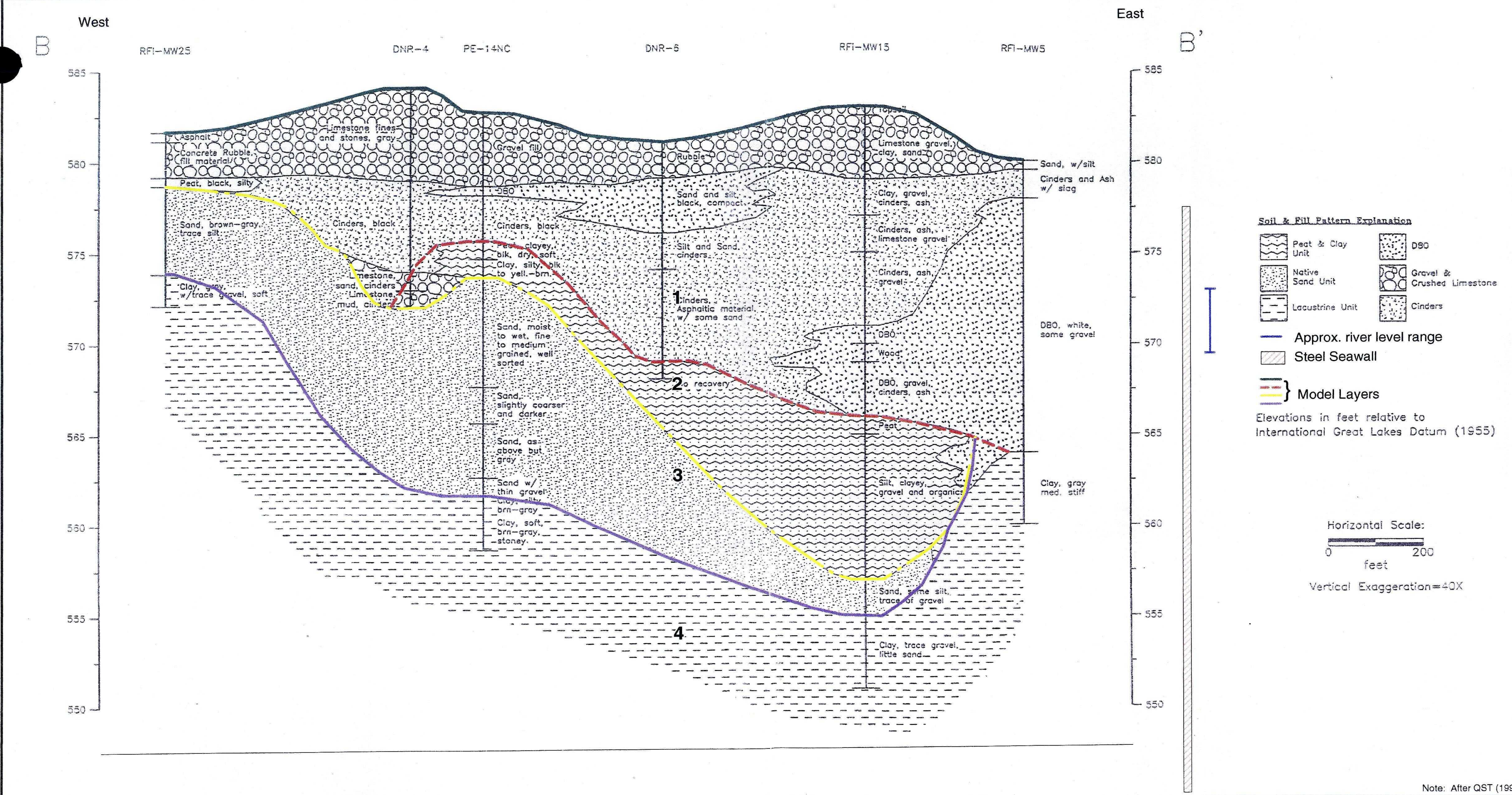
Hydrostratigraphic Cross-Section A-A'

BASF-Wyandotte North Works

Figure 9

CMS Groundwater Modeling

June 2002



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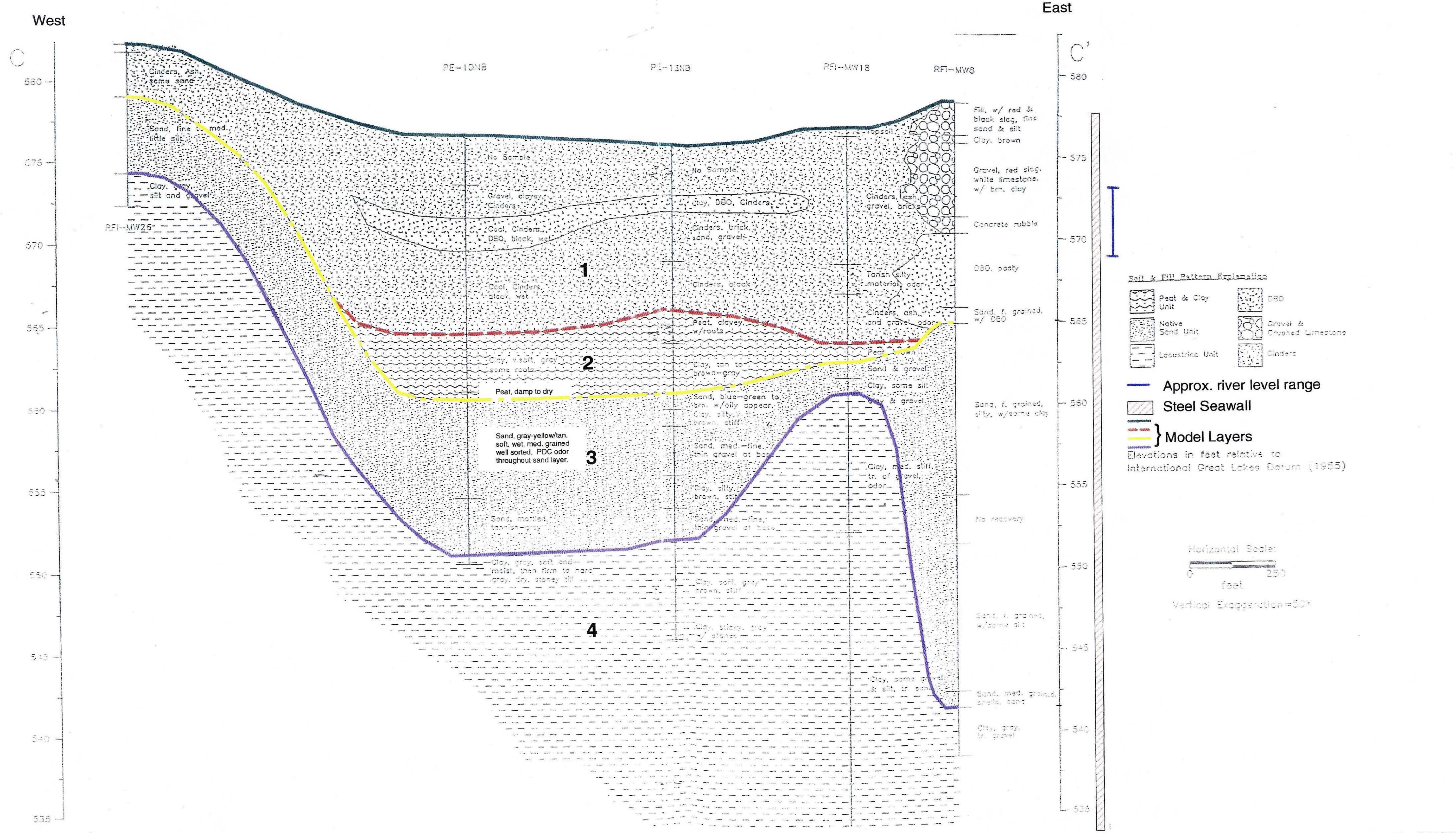
Hydrostratigraphic Cross-Section B-B'

BASF-Wyandotte North Works

Figure 10

CMS Groundwater Modeling

June 2002



Note: After QST (1999)

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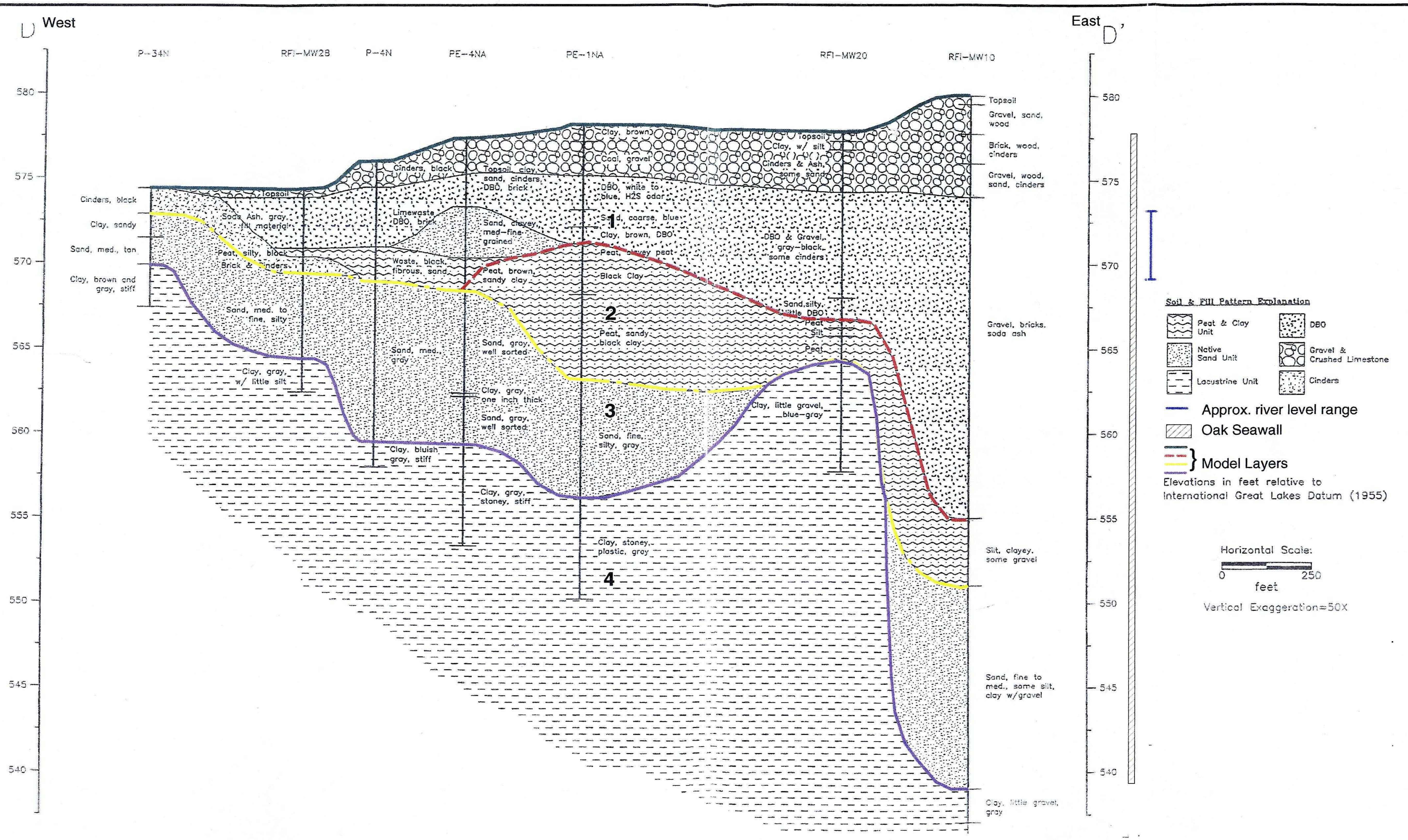
Hydrostratigraphic Cross-Section C-C'
BASF-Wyandotte North Works

Figure 11
CMS Groundwater Modeling
June 2002



Note: After QST (1999)

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Hydrostratigraphic Cross-Section D-D'

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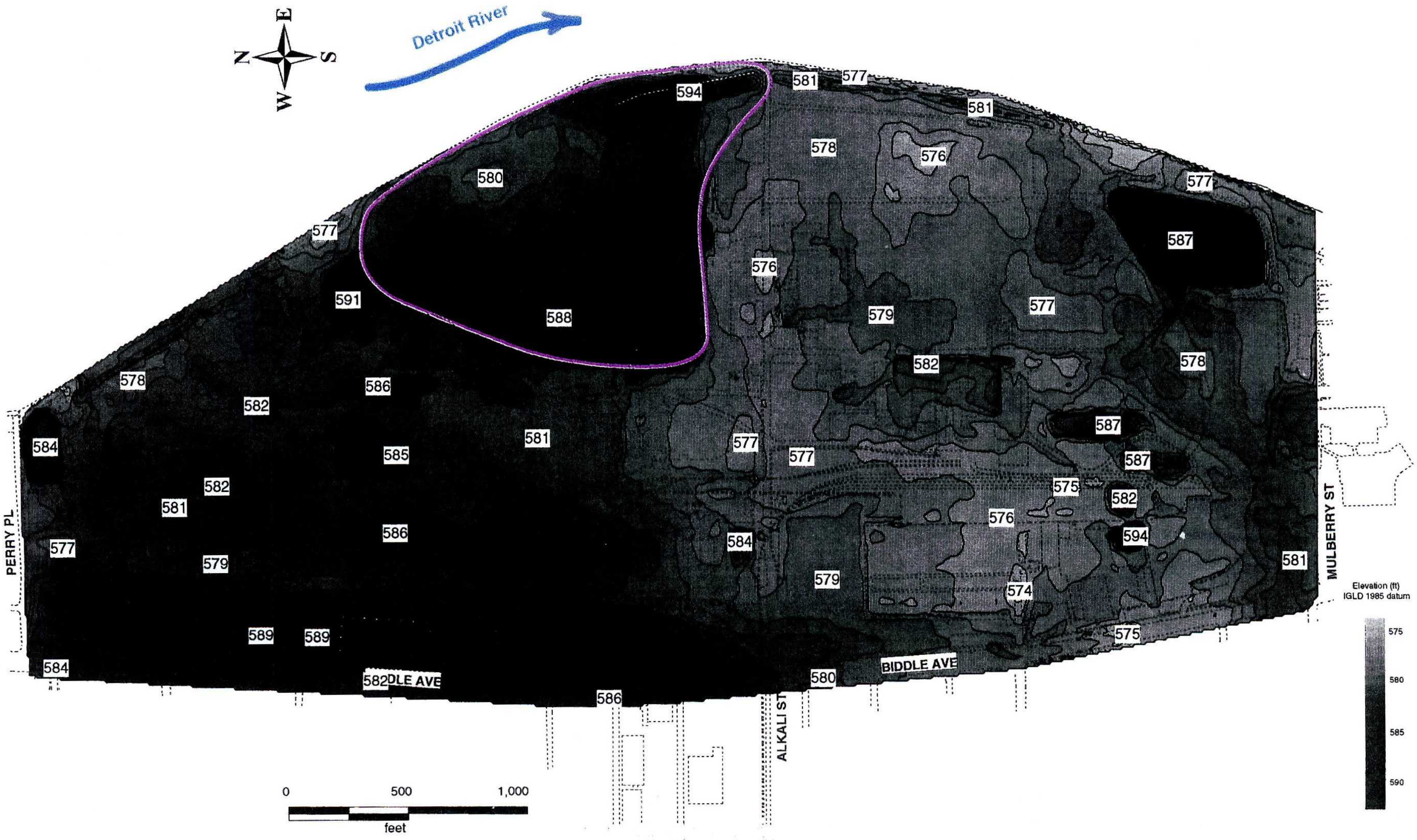
Figure 12

CMS Groundwater Modeling

June 2002



575.7 Elevation above IGLD 1985 datum

DBO Disposal Area

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Elevation of Ground Surface

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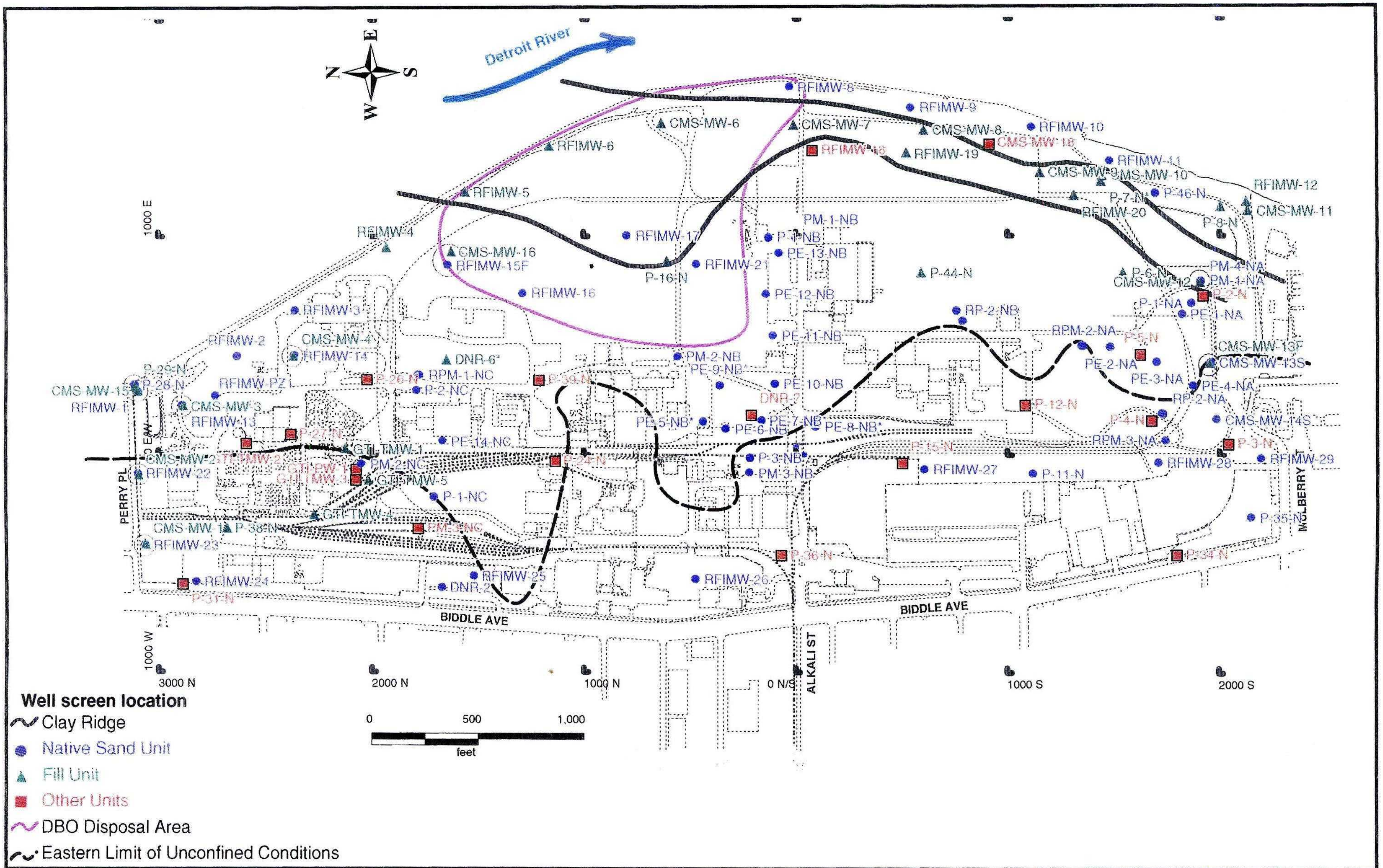
Figure 13

CMS Groundwater Modeling

June 2002



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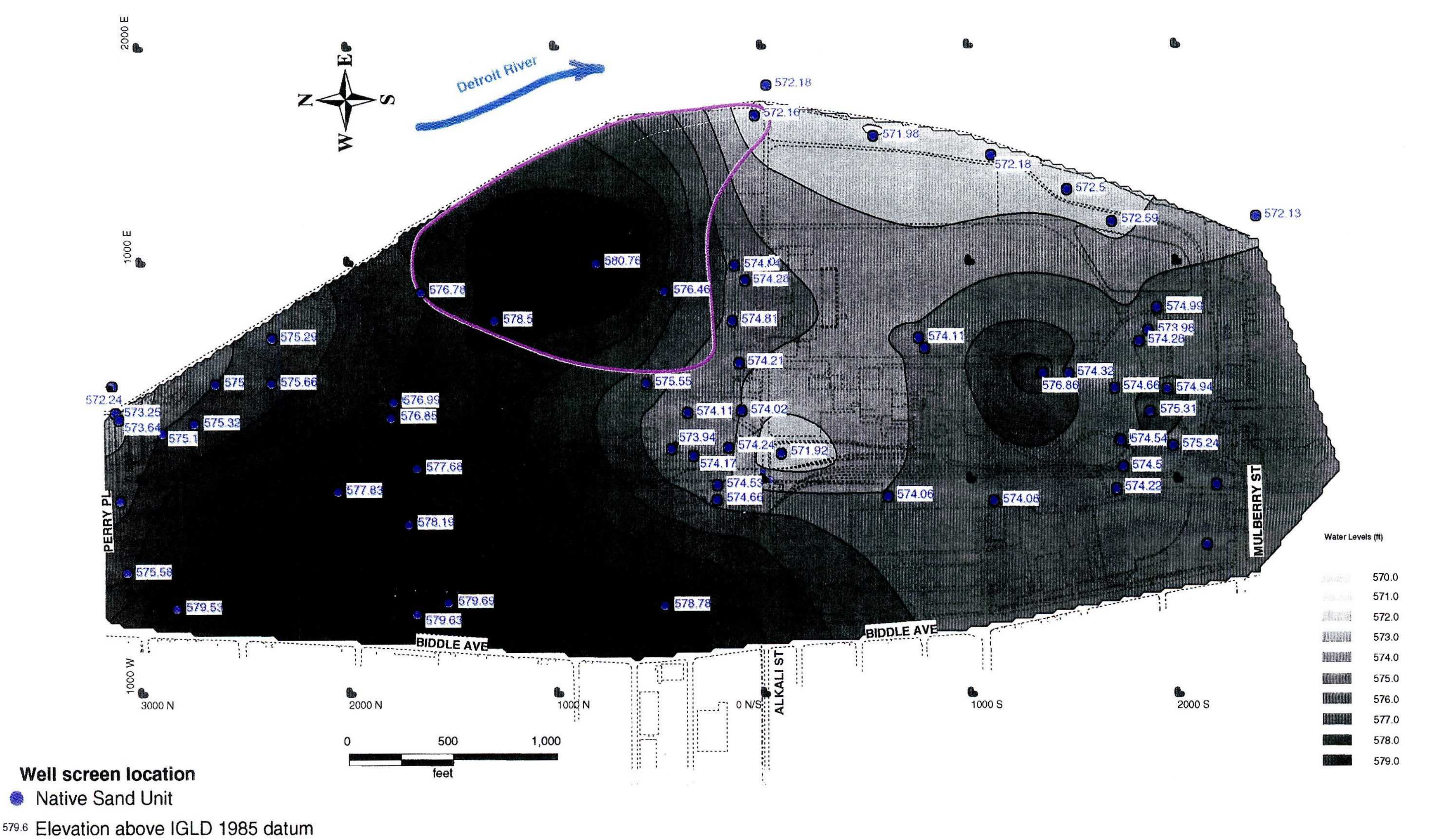
Water Level Monitoring Well Locations

BASF-Wyandotte North Works

Figure 14

CMS Groundwater Modeling

June 2002



Note: No elevation indicates that well was not monitored

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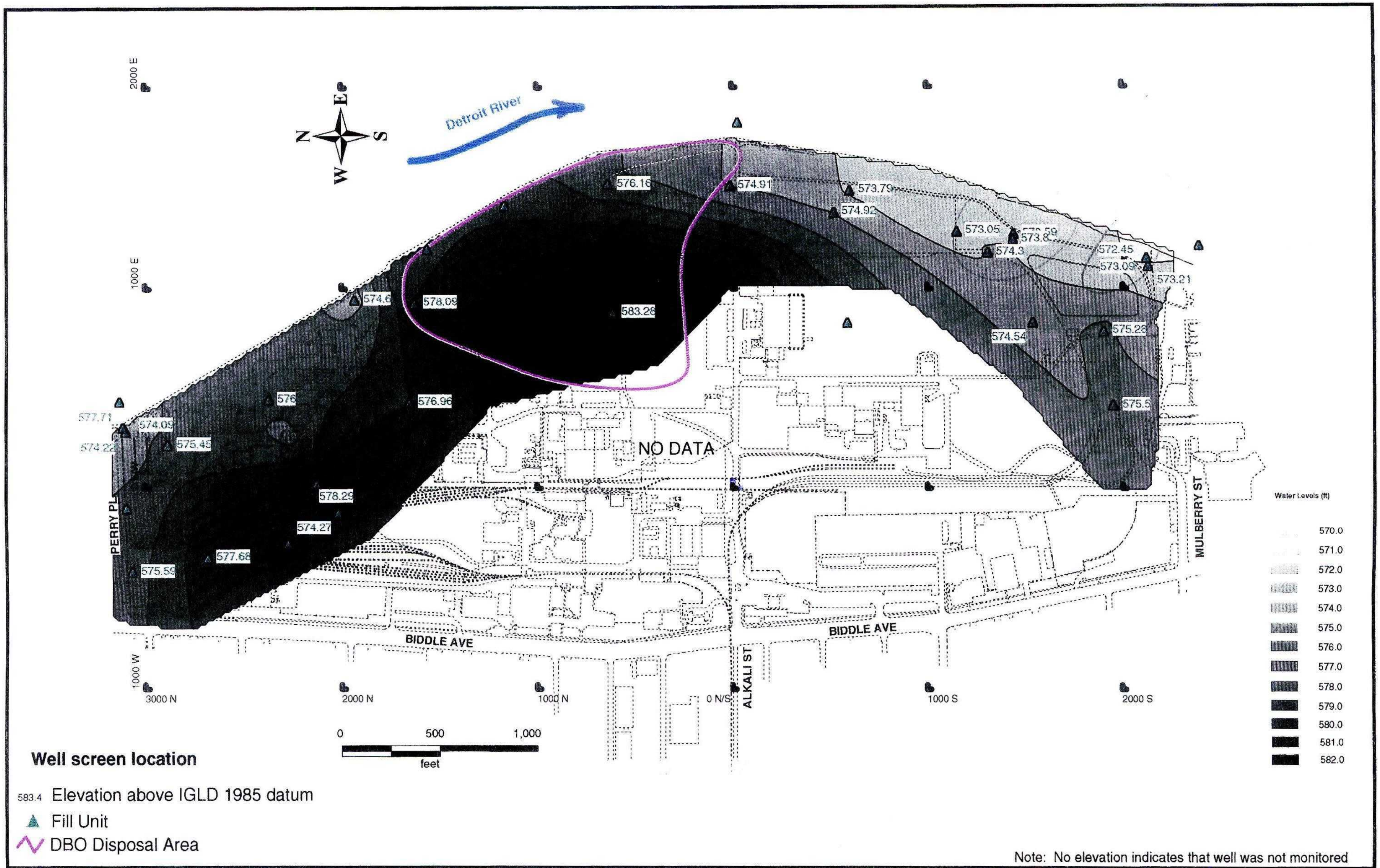
Water Levels for April 2001 in Native Sand Unit

BASF-Wyandotte North Works

Figure 15

CMS Groundwater Modeling

June 2002



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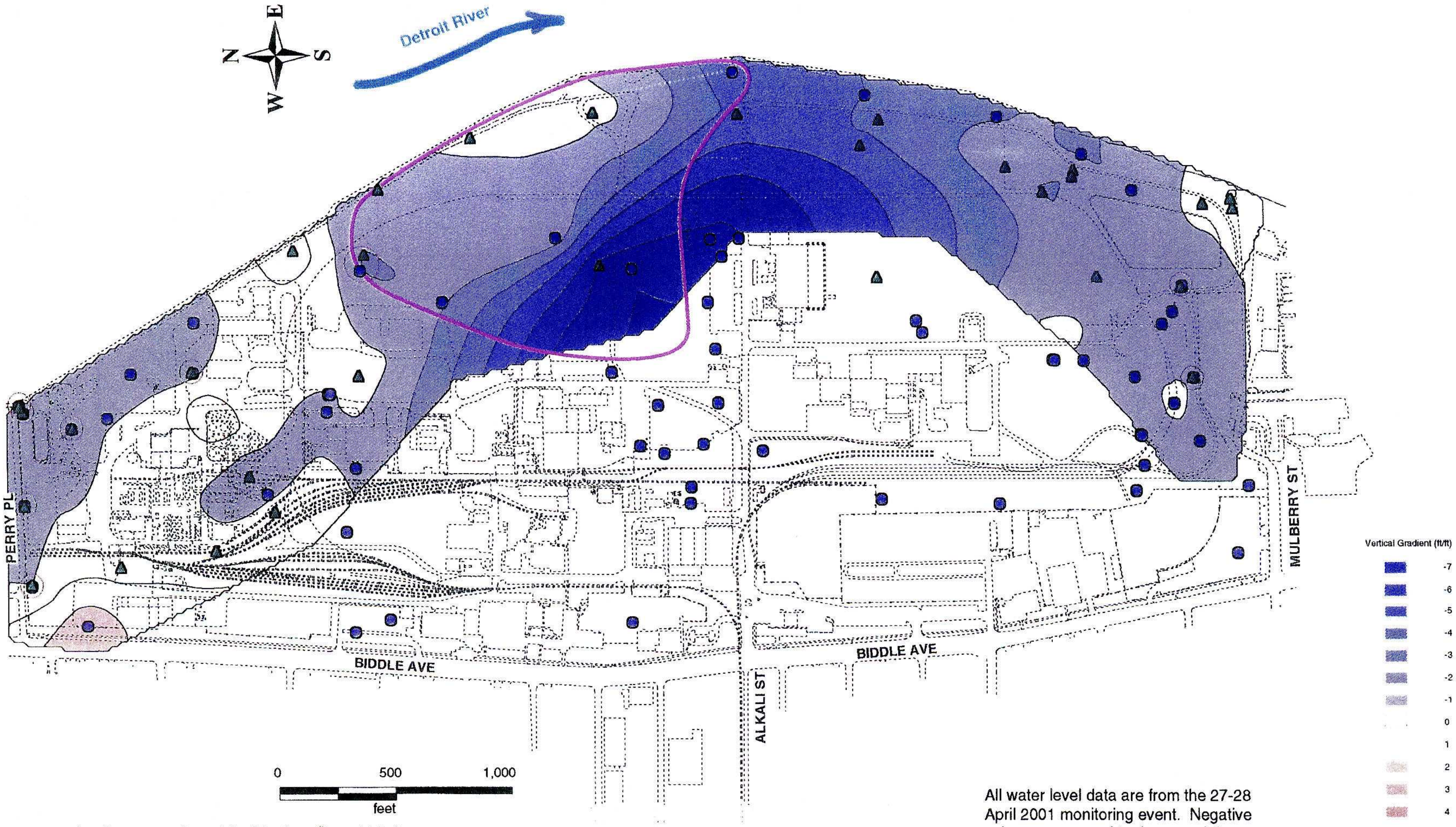
Water Levels for April 2001 in Fill Unit

BASF-Wyandotte North Works

Figure 16

CMS Groundwater Modeling

June 2002



● Measurement point for waterlevel in Native Sand Unit

▲ Measurement point for waterlevel in Fill Unit

○ Multi-level Well Pair

All water level data are from the 27-28 April 2001 monitoring event. Negative values correspond to downward flow from the Fill to the Native Sand. Positive values correspond to upward flow from the Native Sand to the Fill.

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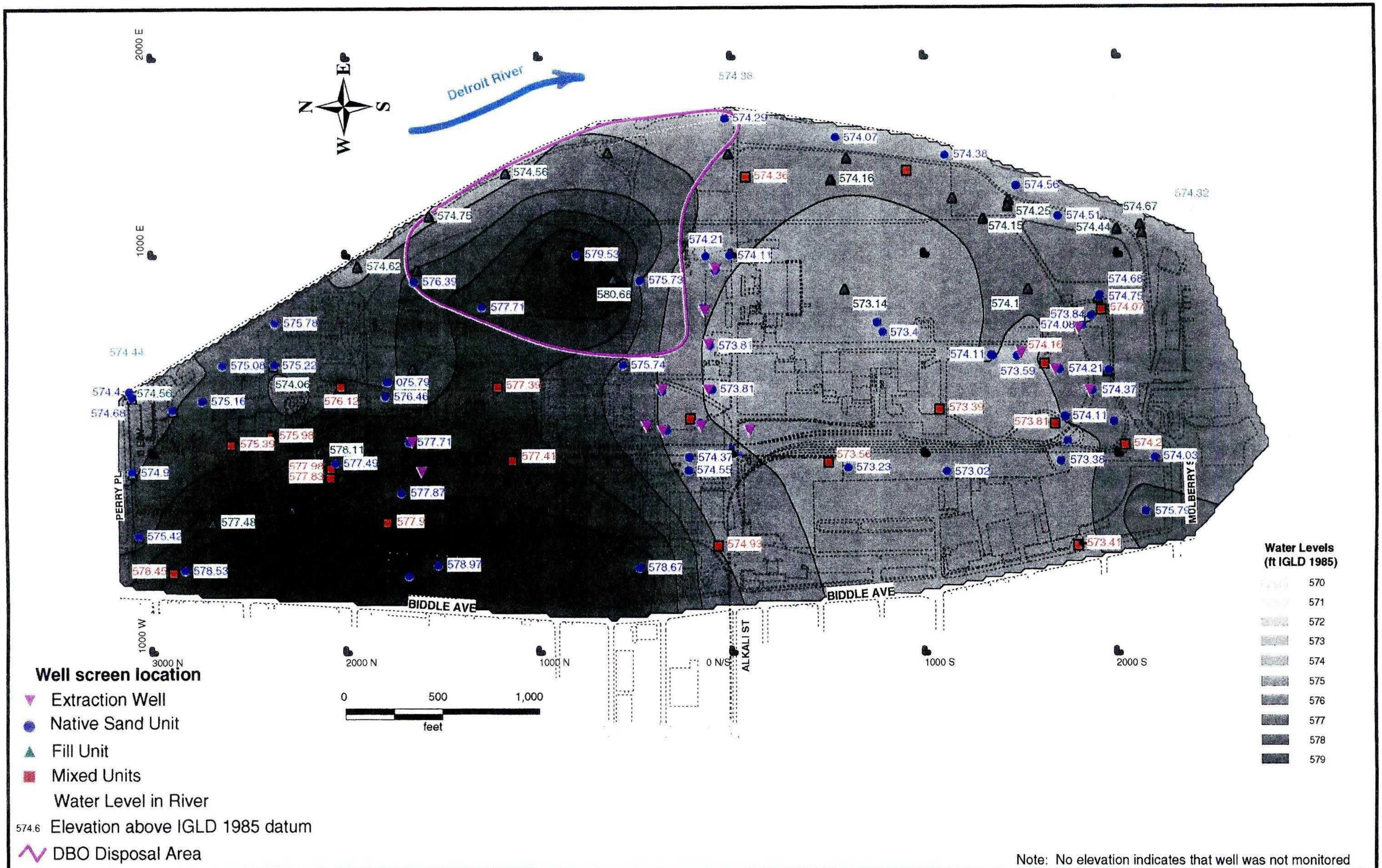
Vertical Flow Direction

BASF-Wyandotte North Works

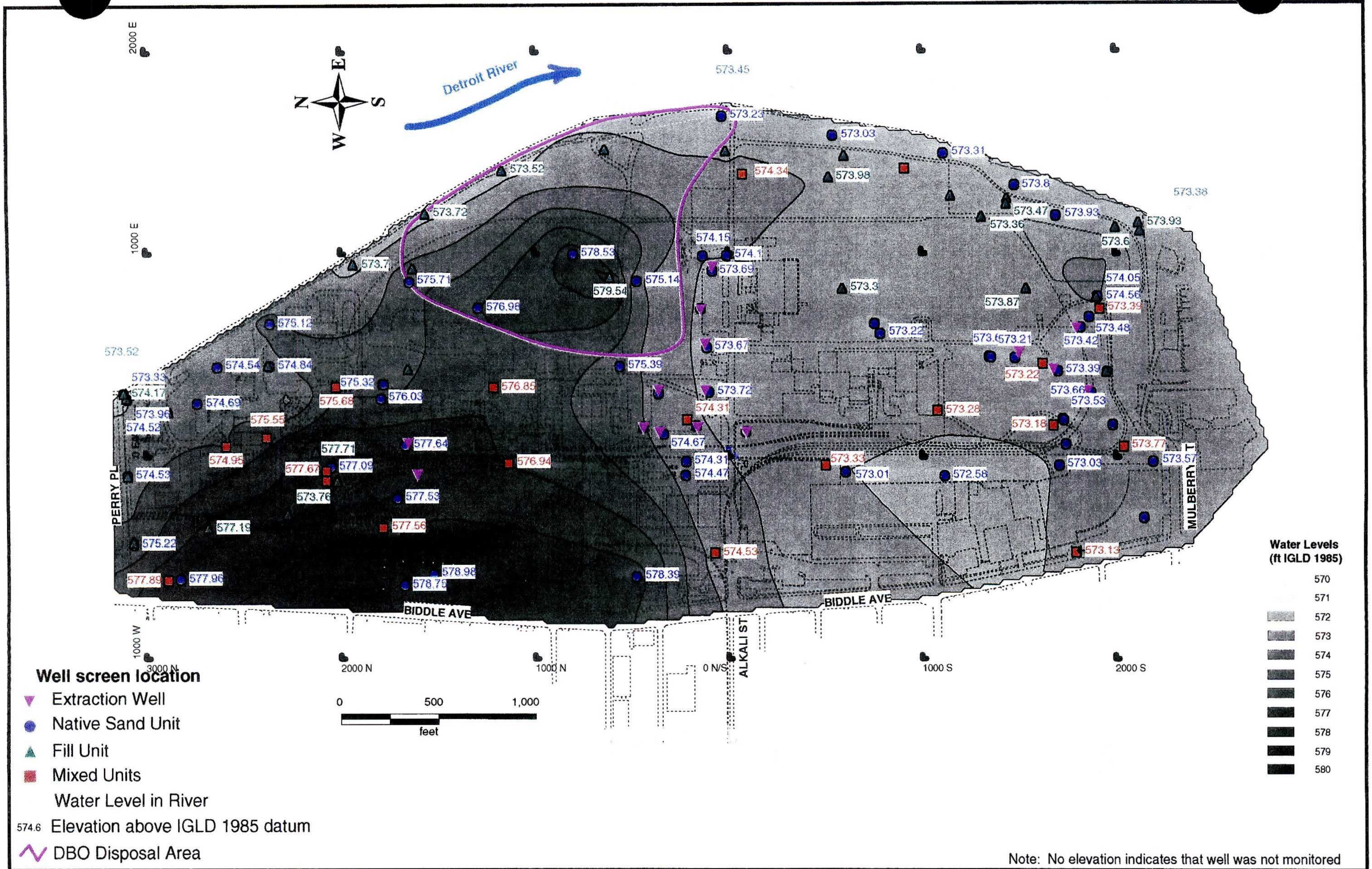
Figure 17

CMS Groundwater Modeling

June 2002



waterloo hydrogeologic SOFTWARE · CONSULTING · TRAINING BASF	**Water Levels for July 1998 in All Units** BASF-Wyandotte North Works	**Figure 18** CMS Groundwater Modeling June 2002



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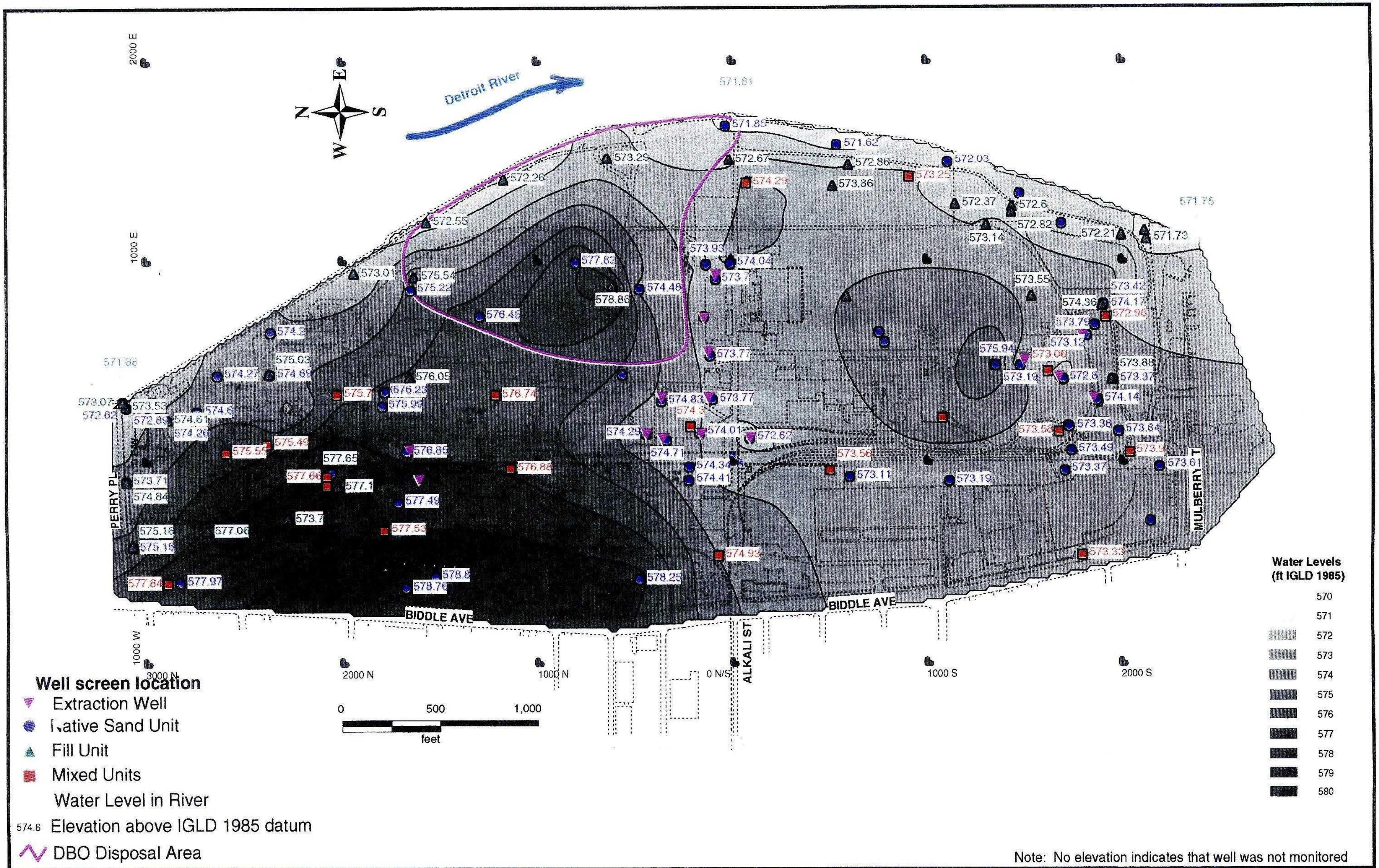
Water Levels for October 1998 in All Units

BASF-Wyandotte North Works

Figure 19

CMS Groundwater Modeling

June 2002



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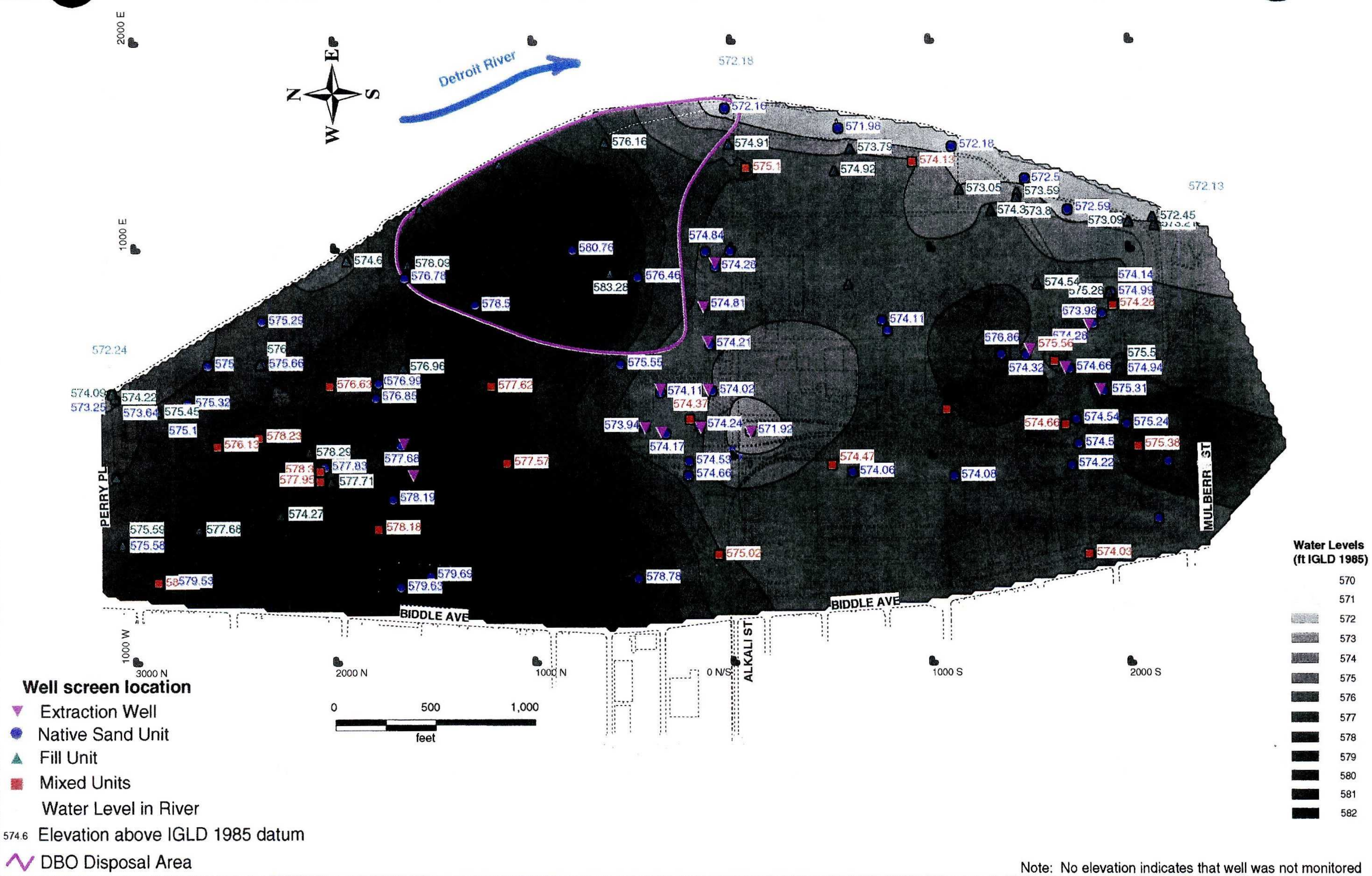
Water Levels for December 1999 in All Units

BASF-Wyandotte North Works

Figure 20

CMS Groundwater Modeling

June 2002



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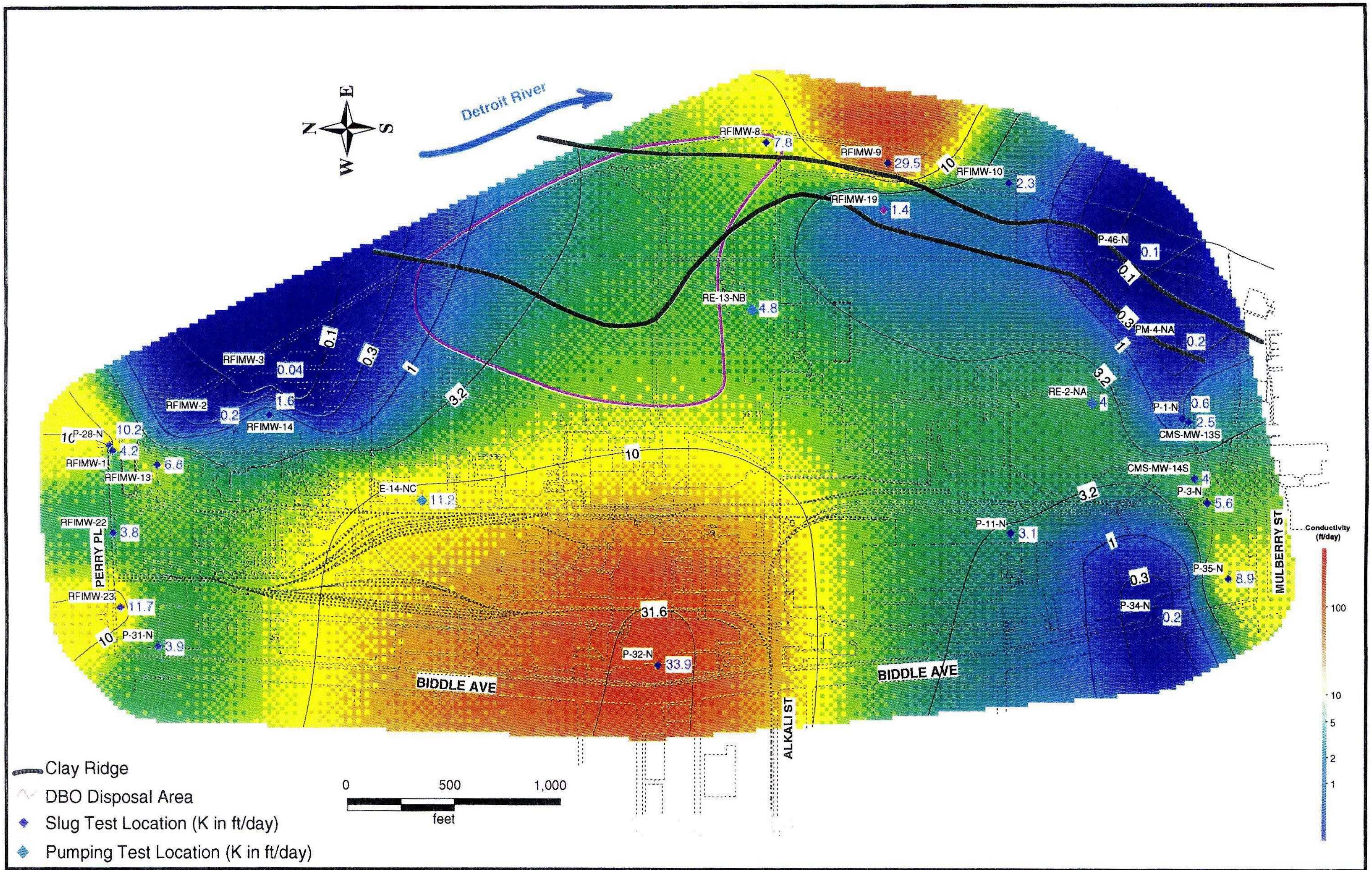
Water Levels for April 2001 in All Units

BASF-Wyandotte North Works

Figure 21

CMS Groundwater Modeling

June 2002



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BASF

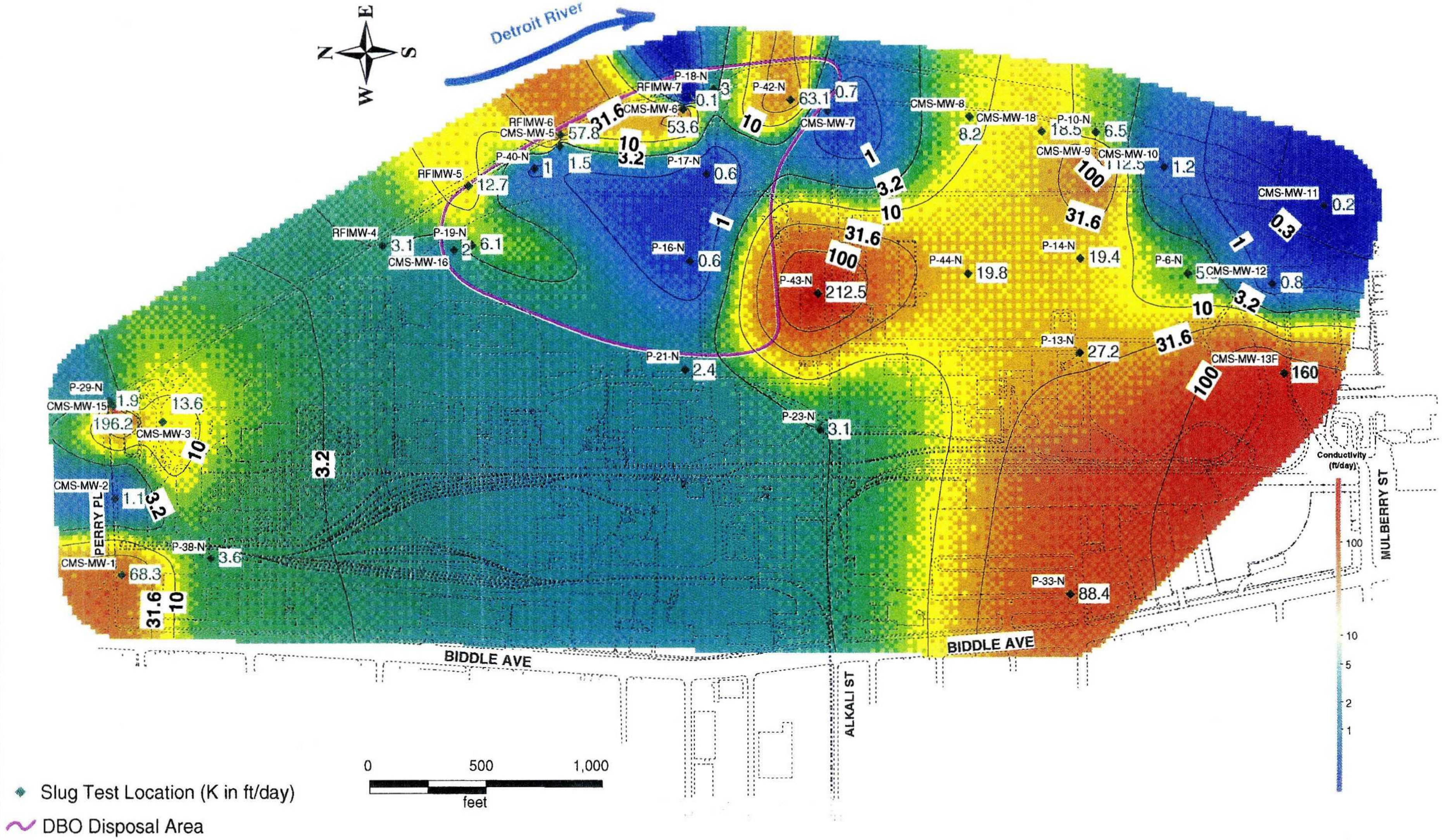
Hydraulic Conductivity of Native Sand Unit (ft/day)

BASF-Wyandotte North Works

Figure 22

CMS Groundwater Modeling

June 2002



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BASF

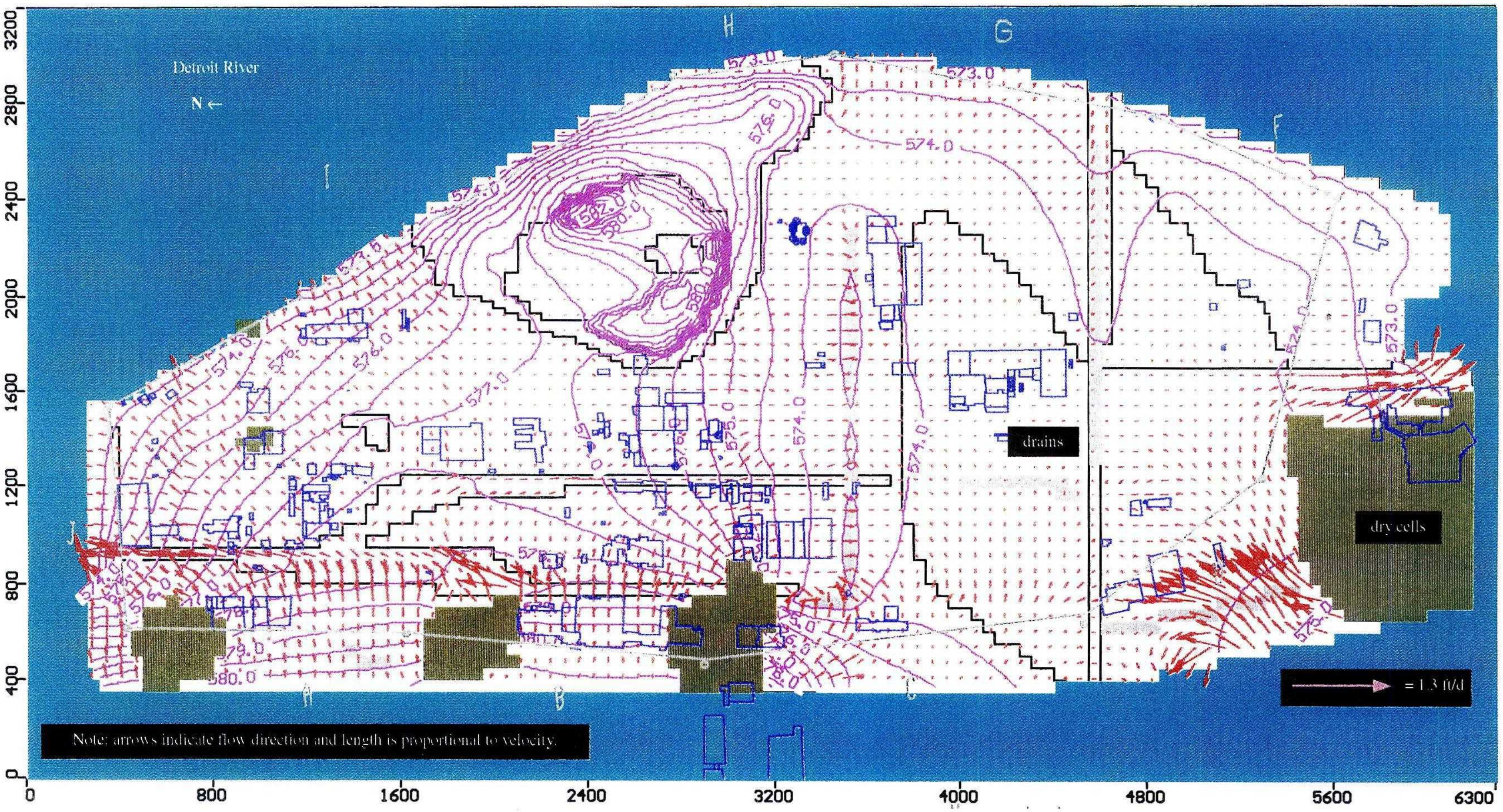
Hydraulic Conductivity of Fill Unit (ft/day)

BASF-Wyandotte North Works

Figure 23

CMS Groundwater Modeling

June 2002



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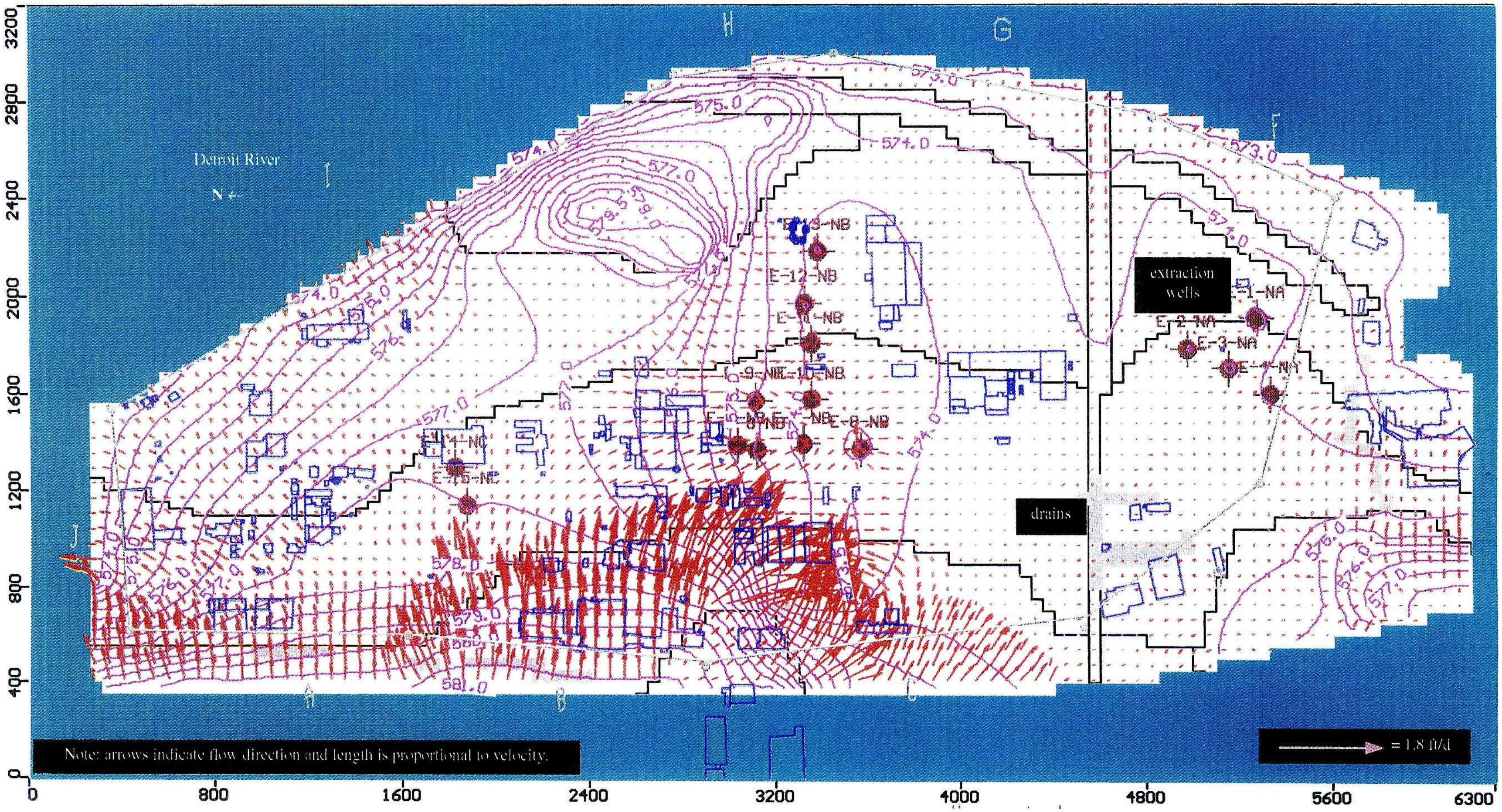
Predicted Water Levels and Flow Velocities – Fill Unit

BASF-Wyandotte North Works

Figure 38

CMS Groundwater Modeling

June 2002



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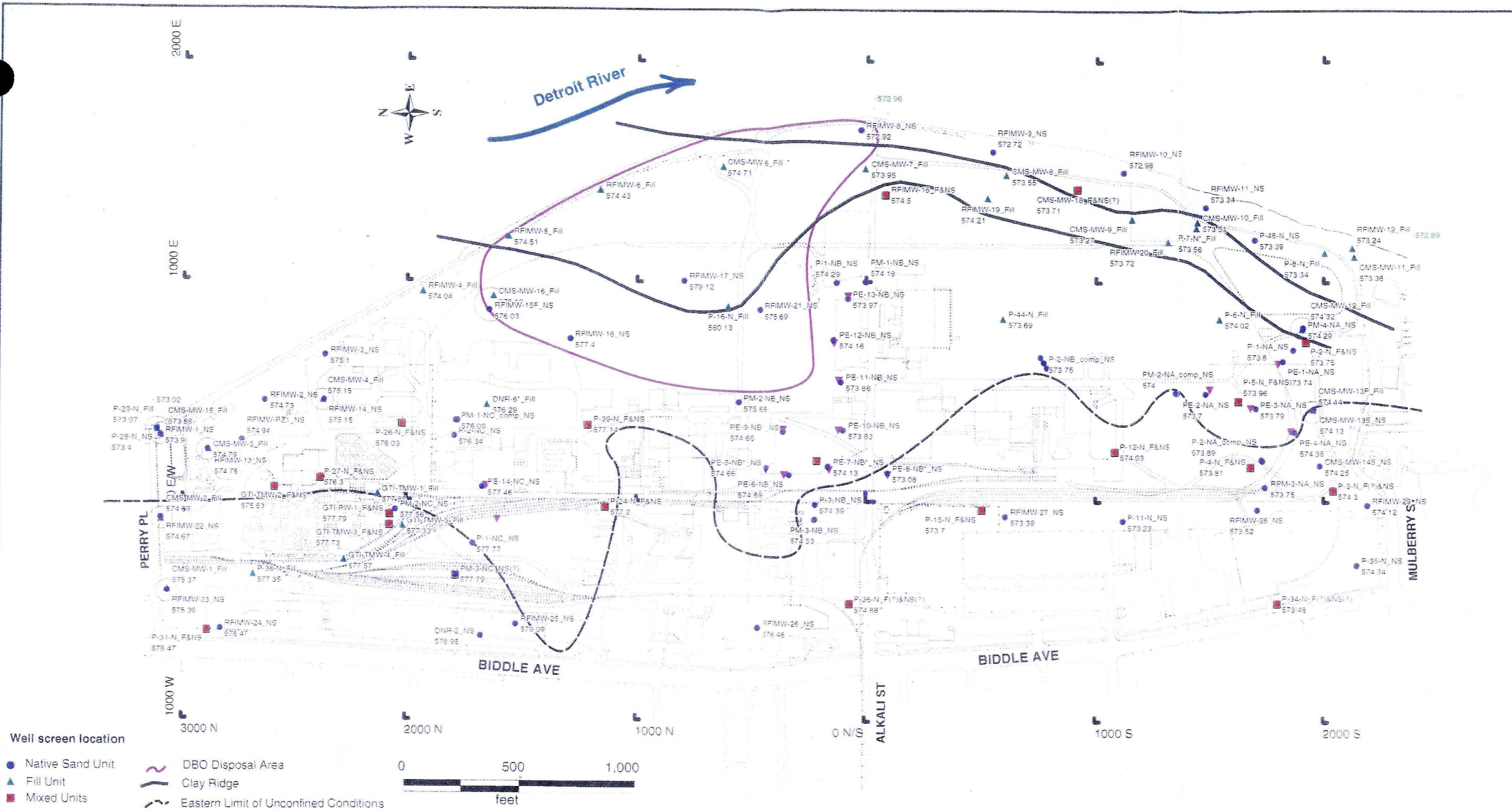
Predicted Water Levels and Flow Velocities – Native Sand Unit

BASF-Wyandotte North Works

Figure 39

CMS Groundwater Modeling

June 2002



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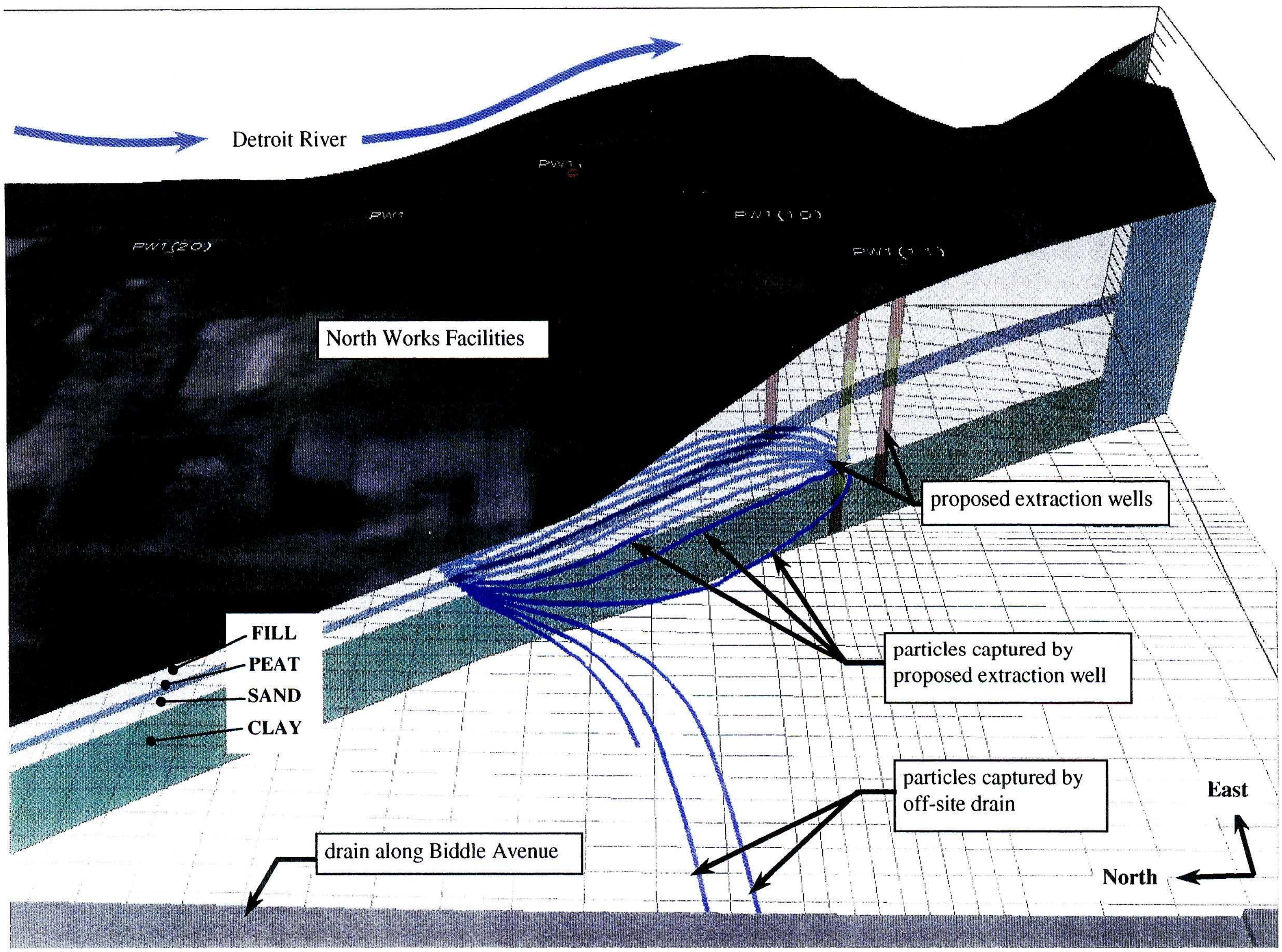
Water Level Calibration Points

BASF-Wyandotte North Works

Figure 43

CMS Groundwater Modeling

June 2002



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Hypothetical Visualization of Remediation Modeling

BASF-Wyandotte North Works

Figure 57

CMS Groundwater Modeling

June 2002

Appendix B

Hydraulic Conductivity Data

Table B1. Hydraulic Conductivity Data for Native Sand Unit

Location	Screened Unit	Hydraulic Conductivity K (ft / day)	$\log_{10}$ K	
NATIVE SAND				
RFIMW-3	Native Sand	0.04	-1.37	
P-46-N	Native Sand	0.09	-1.06	
P-34-N	F(?)&NS(?)	0.20	-0.70	†
PM-4-NA	Native Sand	0.21	-0.67	
RFIMW-2	Native Sand	0.23	-0.64	
P-1-N	Native Sand	0.63	-0.20	
RFIMW-14	Native Sand	1.59	0.20	
RFIMW-10	Native Sand	2.37	0.37	
CMS-MW-13S	Native Sand	2.54	0.40	
P-11-N	Native Sand	3.13	0.49	
RFIMW-22	Native Sand	3.77	0.58	
P-31-N	F&NS	3.87	0.59	
CMS-MW-14S	Native Sand	4.00	0.60	
RE-2-NA	Native Sand	4.01	0.60	*
RFIMW-1	Native Sand	4.14	0.62	
RE-13-NB	Native Sand	4.75	0.68	*
P-3-N	F(?)&NS	5.65	0.75	
RFIMW-13	Native Sand	6.77	0.83	
RFIMW-8	Native Sand	7.77	0.89	
P-35-N	Native Sand	9.00	0.95	
P-28-N	Native Sand	10.22	1.01	
E-14-NC	Native Sand	11.24	1.05	*
RFIMW-23	Native Sand	11.85	1.07	
RFIMW-9	Native Sand	29.65	1.47	
P-32-N	F(?)&NS	33.71	1.53	

count	25
median	4.00
std.dev. (σ)	5.77
min	0.04
$-1.0\ \sigma$	0.44
geo. mean	**2.53**
$+1.0\ \sigma$	14.57
max	33.71

Notes: * Denotes pumping test data. All other data are from single borehole slug tests.
† The results from this slug test were reanalyzed and support a higher conductivity of 2.0 ft/d.

Table B2. Hydraulic Conductivity Data for Fill Unit

Location	Screened Unit	Hydraulic Conductivity K (ft / day)	$\log_{10}$ K	
FILL				
RFIMW-7	DBO	0.08	-1.12	
CMS-MW-11	Fill	0.22	-0.65	
P-17-N	Fill	0.60	-0.22	
P-16-N	Fill	0.64	-0.19	
CMS-MW-7	Fill	0.69	-0.16	
CMS-MW-12	Fill	0.78	-0.11	
P-40-N	DBO	0.95	-0.02	
CMS-MW-2	Fill	1.13	0.05	
CMS-MW-10	Fill	1.22	0.08	
CMS-MW-5	DBO	1.49	0.17	
P-29-N	Fill	1.94	0.29	
CMS-MW-16	Fill	2.00	0.30	
P-21-N	Fill	2.38	0.38	
P-18-N	Fill	2.99	0.48	
P-23-N	Fill	3.14	0.50	
RFIMW-4	Fill	3.15	0.50	
P-38-N	Fill	3.64	0.56	
P-6-N	Fill	5.33	0.73	
P-19-N	Fill	6.11	0.79	
P-10-N	Fill	6.47	0.81	
CMS-MW-8	Fill	8.25	0.92	
RFIMW-5	DBO	12.70	1.10	
CMS-MW-3	Fill	13.63	1.13	
CMS-MW-18	F&NS (?)	18.48	1.27	
P-14-N	Fill	19.39	1.29	
P-44-N	Fill	19.82	1.30	
P-13-N	Fill	27.25	1.44	
CMS-MW-6	DBO	53.57	1.73	
RFIMW-6	Fill	57.83	1.76	
P-42-N	Fill	63.14	1.80	
CMS-MW-1	Fill	68.31	1.83	
P-33-N	Fill	88.44	1.95	
CMS-MW-9	Fill	112.54	2.05	
CMS-MW-13F	Fill	160.00	2.20	‡
CMS-MW-15	Fill	196.16	2.29	
P-43-N	Fill	212.48	2.33	

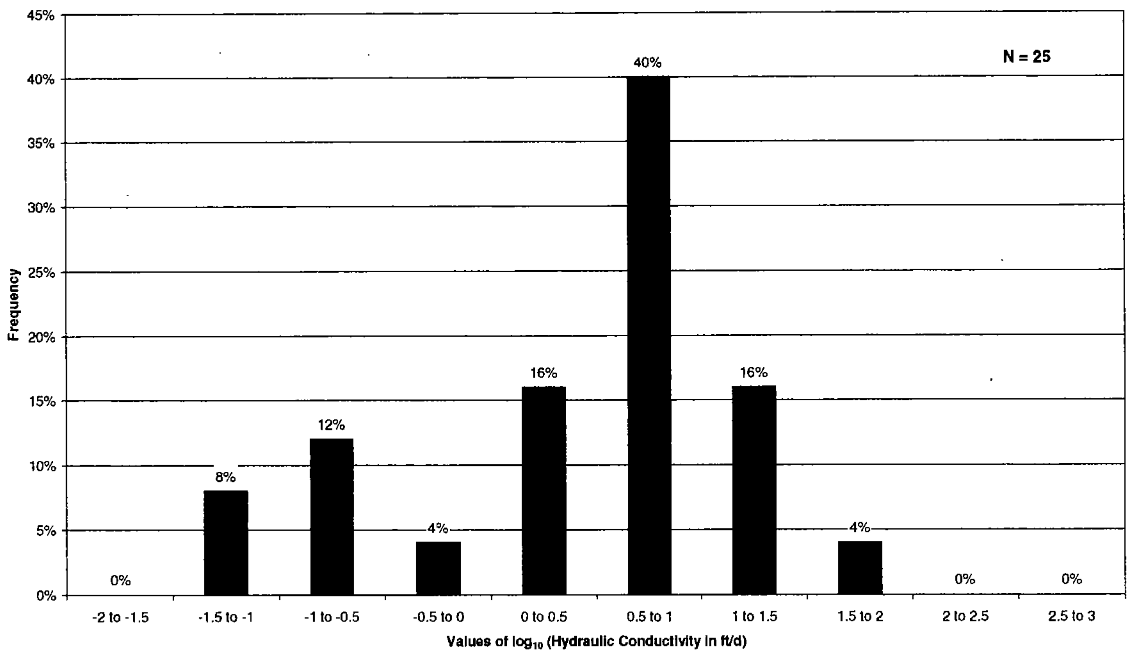
count	36
median	5.71
std.dev. (σ)	7.65
min	0.08
$-1.0\ \sigma$	0.87
geo. mean	**6.62**
$+1.0\ \sigma$	50.63
max	212.48

Notes: All data are from single borehole slug tests.
‡ The results from this slug test were reanalyzed and support a conductivity of 160 ft/d, significantly lower than the previously published estimate of 470 ft/d.

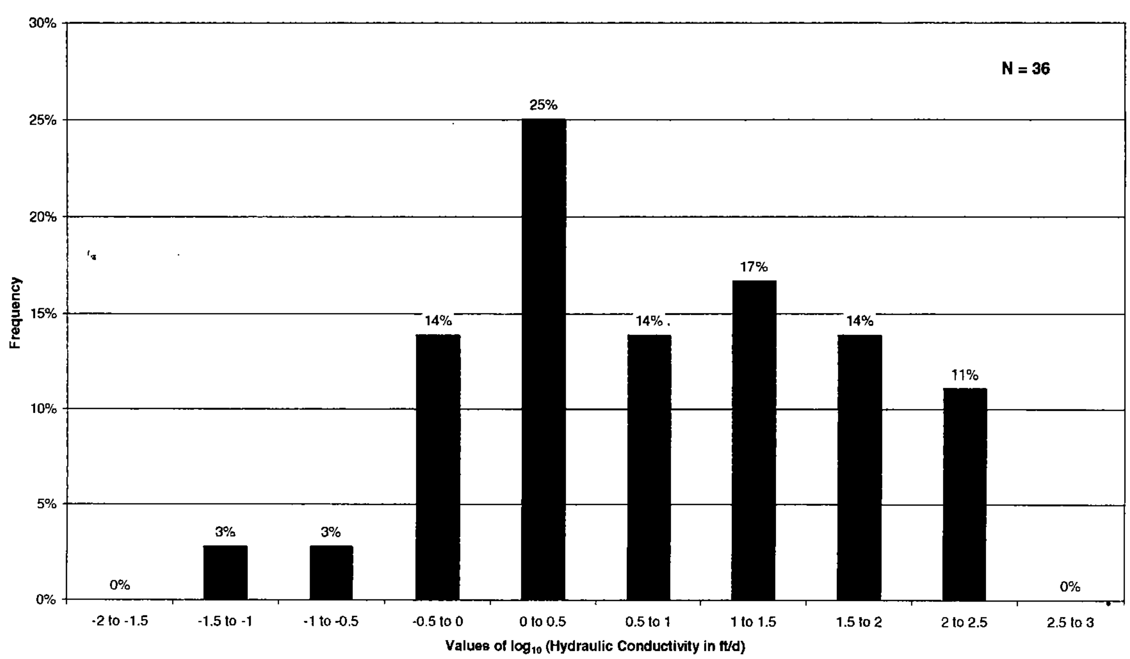
Table B3. Hydraulic Conductivity Data for Mixed or Uncertain Units

Location	Screened Unit	Hydraulic Conductivity K (ft / day)	$\log_{10} K$
MIXED / UNCERTAIN			
P-5-N	F&NS	0.15	-0.82
P-4-N	F&NS	0.54	-0.27
P-2-N	F&NS	0.93	-0.03
P-27-N	F&NS	1.99	0.30
P-26-N	F&NS	2.28	0.36
P-30-N	F&NS	2.31	0.36
P-22-N	F&NS	2.32	0.37
P-20-N	F&NS	2.55	0.41
P-36-N	F(?)&NS(?)	2.80	0.45
P-39-N	F&NS	3.69	0.57
P-12-N	F&NS	7.69	0.89
P-24-N	F&NS	10.70	1.03
P-15-N	F&NS	30.92	1.49
P-25-N	F&NS	120.71	2.08
P-37-N	F&NS	150.98	2.18

count	15
median	2.55
std.dev. (σ)	6.49
min	0.15
$-1.0\,\sigma$	0.65
geo. mean	**4.20**
$+1.0\,\sigma$	27.27
max	150.98



Graph B1. Distribution of Values of $\log_{10}$ Hydraulic Conductivity of Native Sand Unit



Graph B2. Distribution of Values of $\log_{10}$ Hydraulic Conductivity of Fill Unit

Appendix C

Water Level Calibration Data

Table C1. Calibration Residuals for Monitoring Wells Screened in Fill

Well	X-Model ft S/N	Y-Model ft W/E	X-World ft S/N	Y-World ft W/E	Obs. ft IGLD85	Calc. ft	Calc.-Obs. ft
DNR-6*_Fill	+ 1,826.9	+ 1,663.0	- 1,649.1	+ 436.2	576.29	576.77	0.48
P-44-N_Fill	+ 4,064.3	+ 2,093.1	+ 594.4	+ 833.6	573.69	574.08	0.39
P-6-N_Fill	+ 5,013.8	+ 2,107.6	+ 1,544.1	+ 834.2	574.02	574.35	0.33
GTI-TMW-5_Fill	+ 1,471.1	+ 1,103.3	- 2,013.0	- 118.3	577.33	577.66	0.32
CMS-MW-6_Fill	+ 2,828.2	+ 2,760.1	- 631.9	+ 1,518.6	574.71	574.92	0.22
CMS-MW-10_Fill	+ 4,908.8	+ 2,547.4	+ 1,445.5	+ 1,275.4	573.51	573.71	0.20
CMS-MW-8_Fill	+ 4,066.6	+ 2,746.0	+ 606.2	+ 1,486.3	573.55	573.74	0.19
CMS-MW-9_Fill	+ 4,617.7	+ 2,556.0	+ 1,154.5	+ 1,288.4	573.27	573.40	0.14
P-7-N*_Fill	+ 4,904.9	+ 2,521.1	+ 1,441.2	+ 1,249.2	573.58	573.71	0.13
CMS-MW-4_Fill	+ 1,107.1	+ 1,669.8	- 2,368.6	+ 453.5	575.15	575.23	0.08
GTI-TMW-4_Fill	+ 1,203.5	+ 941.6	- 2,282.9	- 276.1	577.57	577.63	0.06
RFIMW-20_Fill	+ 4,778.2	+ 2,454.9	+ 1,313.5	+ 1,184.9	573.72	573.77	0.05
CMS-MW-16_Fill	+ 1,845.0	+ 2,158.3	- 1,623.7	+ 931.1	576.18	576.21	0.03
P-8-N_Fill	+ 5,470.3	+ 2,414.6	+ 2,005.0	+ 1,134.5	573.34	573.29	-0.05
CMS-MW-1_Fill	+ 425.4	+ 792.2	- 3,063.1	- 414.1	575.37	575.31	-0.06
RFIMW-12_Fill	+ 5,590.4	+ 2,438.6	+ 2,125.5	+ 1,156.8	573.24	573.16	-0.08
CMS-MW-11_Fill	+ 5,598.8	+ 2,398.5	+ 2,133.2	+ 1,116.5	573.36	573.26	-0.10
RFIMW-6_Fill	+ 2,283.7	+ 2,634.3	- 1,178.1	+ 1,400.7	574.43	574.33	-0.11
CMS-MW-7_Fill	+ 3,453.0	+ 2,762.0	- 7.0	+ 1,511.3	573.95	573.82	-0.13
CMS-MW-13F_Fill	+ 5,429.8	+ 1,703.4	+ 1,954.1	+ 423.9	574.14	573.96	-0.18
CMS-MW-12_Fill	+ 5,376.8	+ 2,068.8	+ 1,906.5	+ 790.1	574.32	574.14	-0.18
P-16-N_Fill	+ 2,862.6	+ 2,127.4	- 606.7	+ 885.4	580.13	579.90	-0.23
RFIMW-19_Fill	+ 3,987.2	+ 2,637.9	+ 525.3	+ 1,379.4	574.21	573.98	-0.24
RFIMW-4_Fill	+ 1,531.6	+ 2,185.0	- 1,936.7	+ 962.4	574.04	573.79	-0.25
CMS-MW-15_Fill	+ 381.4	+ 1,498.7	- 3,096.8	+ 293.0	573.88	573.47	-0.41
RFIMW-5_Fill	+ 1,904.4	+ 2,429.4	- 1,560.3	+ 1,201.3	574.51	574.06	-0.45
CMS-MW-3_Fill	+ 595.7	+ 1,434.3	- 2,883.5	+ 225.4	574.79	574.29	-0.50
GTI-TMW-1_Fill	+ 1,357.9	+ 1,248.0	- 2,124.1	+ 28.1	577.85	577.29	-0.56
P-38-N_Fill	+ 807.2	+ 868.6	- 2,680.2	- 343.3	577.35	576.76	-0.59
CMS-MW-2_Fill	+ 391.1	+ 1,112.6	- 3,092.7	- 93.2	574.69	574.09	-0.60
P-29-N_Fill	+ 366.1	+ 1,520.3	- 3,111.8	+ 314.8	573.97	573.27	-0.70

+ = South   + = East
– = North   – = West

N =	31	
$\lvert R_{WL}\rvert_{MAX}$ =	+ 0.70	ft
$R_{WL\,AVG}$ =	- 0.09	ft
$\lvert R_{WL}\rvert_{AVG}$ =	+ 0.26	ft
$\Phi_{WL} = SSR_{WL}$ =	+ 3.18	ft^2
RMS_{WL} =	+ 0.32	ft
WL_{AVG} =	575	ft
$SPAN_{WL}$ =	6.89	ft
$NRMS_{WL}$ =	4.6%	

Table C2. Calibration Residuals for Monitoring Wells Screened in Native Sand

Well	X-Model ft S/N	Y-Model ft W/E	X-World ft S/N	Y-World ft W/E	Obs. ft IGLD85	Calc. ft	Calc.-Obs. ft
P-11-N_NS	+ 4,602.3	+ 1,180.8	+ 1,119.1	- 86.5	573.23	574.02	0.79
RFIMW-28_NS	+ 5,193.4	+ 1,241.8	+ 1,710.9	- 34.1	573.52	574.21	0.70
PM-1-NC_comp_NS	+ 1,698.6	+ 1,589.9	- 1,778.4	+ 364.9	576.09	576.76	0.67
RFIMW-27_NS	+ 4,079.6	+ 1,181.3	+ 596.4	- 78.4	573.39	574.04	0.65
P-2-NC_NS	+ 1,688.5	+ 1,517.7	- 1,789.6	+ 292.9	576.34	576.89	0.55
RPM-3-NA_NS	+ 5,226.3	+ 1,345.8	+ 1,745.4	+ 69.4	573.75	574.18	0.43
PE-2-NA_NS	+ 4,959.2	+ 1,767.1	+ 1,484.4	+ 494.5	573.70	574.06	0.36
RFIMW-9_NS	+ 4,006.1	+ 2,849.6	+ 547.3	+ 1,590.8	572.72	573.09	0.36
P-2-NB_comp_NS	+ 4,247.6	+ 1,897.7	+ 774.9	+ 635.5	573.75	574.06	0.30
RFIMW-15F_NS	+ 1,828.3	+ 2,094.8	- 1,641.3	+ 867.9	576.03	576.32	0.29
P-1-NA_NS	+ 5,340.0	+ 1,971.8	+ 1,868.3	+ 693.7	573.80	574.08	0.28
DNR-2_NS	+ 1,821.3	+ 608.1	- 1,670.0	- 618.5	578.95	579.18	0.24
P-2-NA_comp_NS	+ 5,210.8	+ 1,467.7	+ 1,731.7	+ 191.5	573.89	574.11	0.23
PE-3-NA_NS	+ 5,179.9	+ 1,704.2	+ 1,704.2	+ 428.4	573.79	574.00	0.21
PE-8-NB*_NS	+ 3,576.3	+ 1,382.3	+ 96.1	+ 130.0	573.08	573.29	0.21
PE-1-NA_NS	+ 5,296.1	+ 1,920.9	+ 1,823.5	+ 643.4	573.74	573.93	0.19
PM-3-NC_NS(?)	+ 1,707.6	+ 884.9	- 1,779.6	- 340.1	577.79	577.96	0.17
RFIMW-29_NS	+ 5,677.4	+ 1,269.6	+ 2,195.3	- 13.4	574.12	574.23	0.11
PM-2-NA_comp_NS	+ 4,829.6	+ 1,768.5	+ 1,354.9	+ 497.8	574.00	574.10	0.10
RFIMW-8_NS	+ 3,432.2	+ 2,937.8	- 25.3	+ 1,687.4	572.92	573.02	0.10
RFIMW-10_NS	+ 4,576.4	+ 2,766.9	+ 1,116.3	+ 1,499.8	572.98	573.08	0.09
RFIMW-14_NS	+ 1,112.1	+ 1,669.6	- 2,363.7	+ 453.2	575.15	575.23	0.07
P-46-N_NS	+ 5,162.4	+ 2,470.1	+ 1,697.9	+ 1,194.5	573.39	573.46	0.07
RFIMW-11_NS	+ 4,945.4	+ 2,614.8	+ 1,483.1	+ 1,342.4	573.34	573.38	0.04
P-1-NC_NS	+ 1,777.9	+ 1,028.4	- 1,707.3	- 197.7	577.77	577.79	0.02
RFIMW-25_NS	+ 1,970.8	+ 663.3	- 1,519.7	- 565.5	579.09	579.06	-0.03
PE-11-NB_NS	+ 3,365.7	+ 1,793.8	- 108.4	+ 544.5	573.88	573.81	-0.07
PE-5-NB*_NS	+ 3,042.8	+ 1,396.8	- 437.1	+ 152.3	574.66	574.59	-0.07
RFIMW-23_Clay	+ 425.5	+ 786.6	- 3,063.1	- 419.7	575.39	575.31	-0.08
PM-2-NC_NS	+ 1,435.9	+ 1,176.6	- 2,047.1	- 44.5	577.56	577.47	-0.09
PE-10-NB_NS	+ 3,379.6	+ 1,575.3	- 97.8	+ 325.8	573.83	573.72	-0.11
PE-14-NC_NS	+ 1,815.1	+ 1,288.3	- 1,666.3	+ 61.6	577.46	577.33	-0.13
PM-4-NA_NS	+ 5,382.0	+ 2,070.2	+ 1,911.6	+ 791.4	574.29	574.13	-0.16
CMS-MW-13S_NS	+ 5,434.7	+ 1,704.8	+ 1,959.0	+ 425.3	574.13	573.94	-0.19
PM-1-NA_NS	+ 5,382.0	+ 2,075.3	+ 1,911.7	+ 796.5	574.32	574.13	-0.19
CMS-MW-14S_NS	+ 5,465.2	+ 1,446.8	+ 1,985.7	+ 166.8	574.25	574.06	-0.19
RFIMW-21_NS	+ 3,001.3	+ 2,116.4	- 468.2	+ 872.3	575.69	575.50	-0.19
P-3-NB_NS	+ 3,265.7	+ 1,232.1	- 216.6	- 15.7	574.39	574.20	-0.20
P-28-N_NS	+ 365.5	+ 1,524.7	- 3,112.3	+ 319.3	573.40	573.20	-0.20
RFIMW-17_NS	+ 2,670.9	+ 2,242.1	- 796.7	+ 1,002.9	579.12	578.90	-0.23
PE-6-NB_NS	+ 3,148.6	+ 1,365.8	- 331.8	+ 119.7	574.59	574.33	-0.25
PE-7-NB*_NS	+ 3,318.0	+ 1,407.1	- 161.8	+ 158.5	574.13	573.84	-0.29
PM-3-NB_NS	+ 3,264.0	+ 1,164.3	- 219.4	- 83.5	574.53	574.22	-0.30
PM-2-NB_NS	+ 2,918.4	+ 1,693.7	- 557.2	+ 450.9	575.66	575.35	-0.31
P-1-NB_NS	+ 3,340.2	+ 2,243.2	- 127.4	+ 994.2	574.29	573.97	-0.32
PE-13-NB_NS	+ 3,390.2	+ 2,172.8	- 78.4	+ 923.1	573.97	573.64	-0.33
RFIMW-16_NS	+ 2,184.0	+ 1,970.3	- 1,287.4	+ 738.2	577.40	577.06	-0.34
RFIMW-PZ1_NS	+ 744.5	+ 1,480.3	- 2,734.0	+ 269.3	574.94	574.57	-0.37

Well	X-Model ft S/N	Y-Model ft W/E	X-World ft S/N	Y-World ft W/E	Obs. ft IGLD85	Calc. ft	Calc.-Obs. ft
P-35-N_NS	+ 5,628.2	+ 976.8	+ 2,141.8	- 305.4	575.79	575.42	-0.37
PE-4-NA_NS	+ 5,352.6	+ 1,599.9	+ 1,875.4	+ 321.6	574.35	573.96	-0.39
PM-1-NB_NS	+ 3,463.9	+ 2,249.1	- 3.6	+ 998.3	574.18	573.77	-0.41
PE-12-NB_NS	+ 3,331.9	+ 1,984.4	- 139.5	+ 735.6	574.16	573.73	-0.43
RFIMW-13_NS	+ 591.2	+ 1,434.3	- 2,887.9	+ 225.5	574.78	574.29	-0.49
PE-9-NB*_NS	+ 3,118.8	+ 1,563.9	- 358.7	+ 318.2	574.65	574.15	-0.49
RFIMW-1_NS	+ 382.3	+ 1,495.0	- 3,095.9	+ 289.3	573.90	573.40	-0.50
RFIMW-26_NS	+ 3,015.9	+ 665.6	- 474.7	- 578.5	578.48	577.95	-0.53
RFIMW-3_NS	+ 1,113.1	+ 1,875.7	- 2,359.7	+ 659.3	575.10	574.52	-0.58
RFIMW-22_NS	+ 389.9	+ 1,118.3	- 3,093.8	- 87.5	574.67	574.03	-0.64
RFIMW-2_NS	+ 844.7	+ 1,662.2	- 2,631.1	+ 449.7	574.73	574.09	-0.64
RFIMW-24_NS	+ 666.7	+ 619.3	- 2,824.4	- 590.5	578.47	577.65	-0.82

+ = South   + = East
− = North   − = West

N =	60	
$\lvert R_{WL} \rvert_{MAX}$ =	+ 0.82	ft
$R_{WL\ AVG}$ =	- 0.06	ft
$\lvert R_{WL} \rvert_{AVG}$ =	+ 0.30	ft
$\Phi_{WL} = SSR_{WL}$ =	+ 7.91	ft²
RMS_{WL} =	+ 0.36	ft
WL_{AVG} =	575	ft
$SPAN_{WL}$ =	6.40	ft
$NRMS_{WL}$ =	5.7%	

Table C3. Calibration Residuals for Monitoring Wells Screened in Mixed or Uncertain Units

Well	X-Model ft S/N	Y-Model ft W/E	X-World ft S/N	Y-World ft W/E	Obs. ft IGLD85	Calc. ft	Calc.-Obs. ft
P-34-N_F(?)&NS(?)	+ 5,289.1	+ 818.1	+ 1,800.5	- 459.2	573.48	574.52	1.04
P-26-N_F&NS	+ 1,457.4	+ 1,572.0	- 2,019.8	+ 350.5	576.03	576.48	0.45
GTI-TMW-2_F&NS	+ 895.8	+ 1,270.7	- 2,585.7	+ 57.5	575.53	575.94	0.41
P-2-N_F&NS	+ 5,394.7	+ 2,012.1	+ 1,923.5	+ 733.1	573.75	574.10	0.35
P-15-N_F&NS	+ 3,989.1	+ 1,225.3	+ 506.5	- 33.1	573.70	574.03	0.33
P-4-N_F&NS	+ 5,161.7	+ 1,439.1	+ 1,682.2	+ 163.6	573.81	574.14	0.33
P-27-N_F&NS	+ 1,102.8	+ 1,316.6	- 2,378.1	+ 100.3	576.30	576.46	0.15
P-5-N_F&NS	+ 5,103.3	+ 1,739.0	+ 1,628.2	+ 464.3	573.96	574.05	0.09
P-12-N_F&NS	+ 4,563.2	+ 1,500.5	+ 1,084.6	+ 233.8	574.03	574.06	0.03
P-24-N_F&NS	+ 2,350.0	+ 1,210.0	- 1,132.6	- 24.4	577.20	577.20	0.00
P-39-N_F&NS	+ 2,268.5	+ 1,581.6	- 1,208.7	+ 348.3	577.14	577.02	-0.12
GTI-TMW-3_F&NS	+ 1,412.4	+ 1,108.7	- 2,071.6	- 112.0	577.73	577.60	-0.13
P-3-N_F(?)&NS	+ 5,525.4	+ 1,338.4	+ 2,044.3	+ 57.6	574.30	574.16	-0.13
CMS-MW-18_F&NS(?)	+ 4,379.6	+ 2,690.2	+ 918.4	+ 1,426.0	573.71	573.52	-0.20
GTI-PW-1_F&NS	+ 1,412.4	+ 1,157.4	- 2,070.8	- 63.4	577.79	577.47	-0.32
RFIMW-18_F&NS	+ 3,542.9	+ 2,648.5	+ 81.1	+ 1,396.5	574.50	574.06	-0.44
P-31-N_F&NS	+ 605.4	+ 612.7	- 2,885.8	- 596.2	578.47	577.43	-1.04
P-36-N_F(?)&NS(?	+ 3,421.6	+ 787.1	- 67.3	- 463.0	574.88	573.71	-1.17

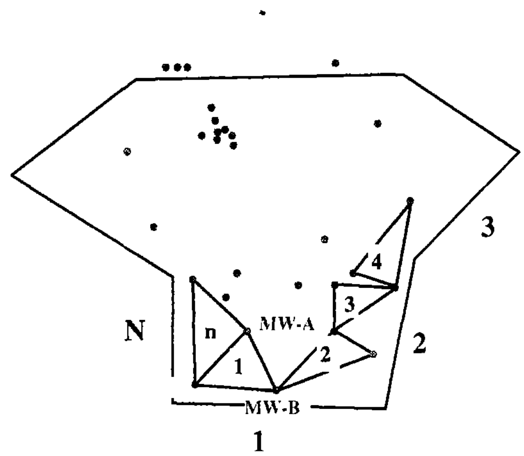
+ = South　　+ = East
– = North　　– = West

N =	18	
$\lvert R_{WL}\rvert_{MAX}$ =	+ 1.17	ft
$R_{WL\,AVG}$ =	- 0.02	ft
$\lvert R_{WL}\rvert_{AVG}$ =	+ 0.37415	ft
$\Phi_{WL} = SSR_{WL}$ =	+ 4.66	ft²
RMS_{WL} =	+ 0.51	ft
WL_{AVG} =	575	ft
$SPAN_{WL}$ =	4.99	ft
$NRMS_{WL}$ =	10.2%	

Appendix D

Boundary Flux Calculations

METHODOLOGY



PLAN VIEW

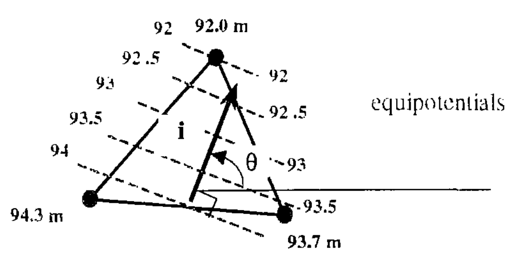
Given:

(closed) boundary : 1,2,3, ... , N

monitoring wells : MW-A, MW-B, MW-C, ... each with coordinates x,y and water level h

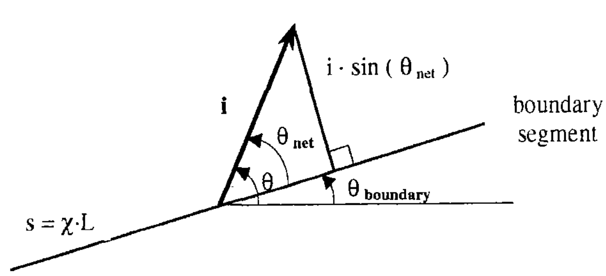
triangulation units : Δ1, Δ2, Δ3, ... , Δn formed from monitoring wells screened in specific geologic units

From (x,y,h) data and for each triangle (Δ),
calculate hydraulic gradient **i** and angle of hydraulic gradient θ. (calculated using a 3x3 matrix in Excel)



For each boundary segment, assign a proportion χ ($0<\chi<1$) to each triangulation unit (Δ) corresponding to the proportion of the length (L) of the boundary segment that it represents. E.g., for boundary segment 2, **Δ2** appears to represent the hydraulic gradient along about 45% of its length; **Δ3**, 35 %, and **Δ4**, 20%. These proportions should normally sum to 100% for each segment ($\Sigma\chi = 1.0$). Note that a triangulation unit may correspond to more than one segment, e.g., **Δ4** above contributes to both segments 2 and 3.

Also, for each boundary segment, calculate the component of hydraulic gradient ***perpendicular*** to the boundary segment, using the sine of the net angle ($\theta_{net} = \theta - \theta_{boundary}$).



For each boundary segment, use GIS to interpolate thickness (b) and conductivity (K) along the segment. Using the depth to water (ground elevation – water level elevation) data, use GIS to interpolate saturated thickness (b_{sat}) along each segment.

For each boundary segment, calculate an average thickness ($b_{sat\,j}$) and conductivity (K_j) – arithmetic average – along the portion of the segment corresponding to Δ**j**. Use proportion χ_j to calculate the appropriate spatial limits.

incremental flow through portion j of each boundary segment,
$\Delta Q_j = K_j \cdot i_{\perp j} \cdot A_j$
dimensionally, $[L^3/T] = [L/T] \cdot [L/L] \cdot [L^2]$
$K_j = f(\chi_j)$
$b_j = f(\chi_j)$
$i_{\perp j} = i_j \sin(\theta_{net\,j})$
$A_j = b_j \cdot s_j = b_{sat\,j} \cdot L \cdot \chi_j$

Note that this is equivalent to $\Delta Q_j = T_j \cdot i_{\perp j} \cdot s_j$, where transmissivity $T = K \cdot b_{sat}$

APPLICATION

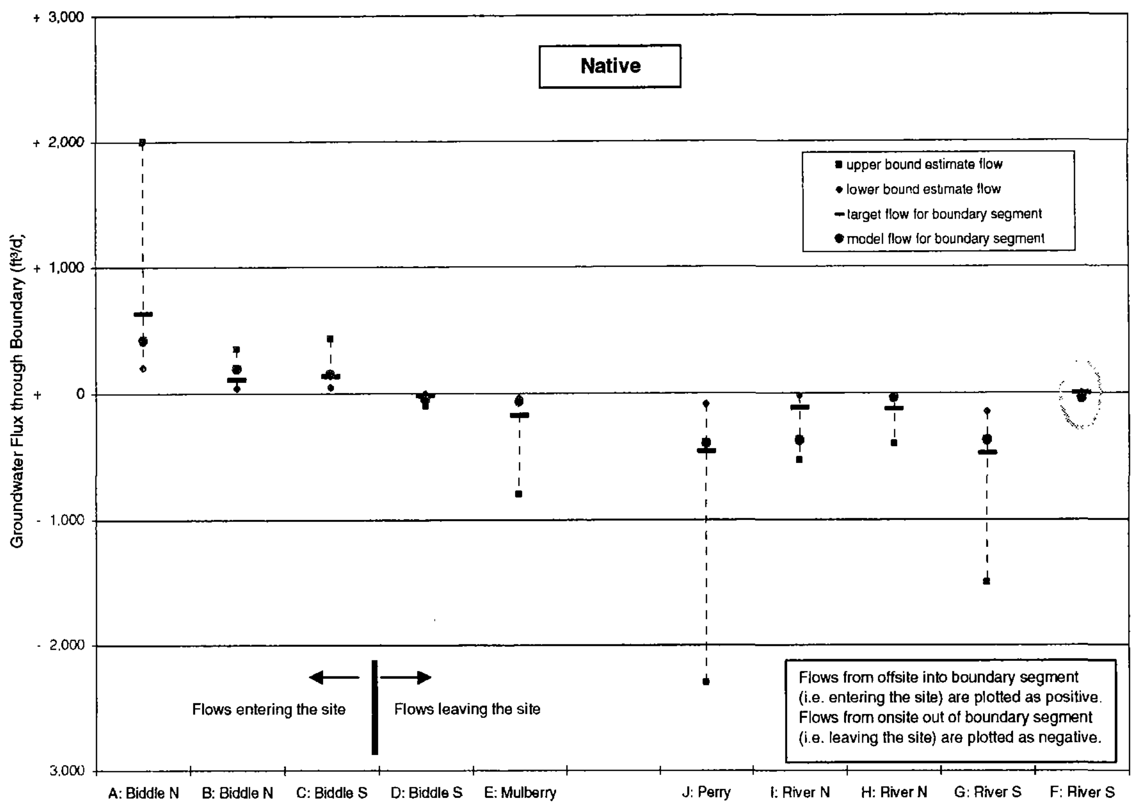
This methodology was applied in the current project for the BASF North Works site by first defining a boundary around the site within which data existed. 10 segments are used, labeled A through J. Monitoring data from February 2002 was used to define 32 triangulation units in the Fill, and 24 in the Native Sand, to calculate the magnitude and direction of the hydraulic gradient. Values of K and b are based on the associated figures in the present report, with b being adjusted downward using the water level data to correspond to b_{sat}. Calculations were carried out segment by segment, and unit by unit. Numerical integration of transmissivity used an arbitrary 100 sub-segments per boundary segment – because of this, the value of T does not exactly equal $K \cdot b_{sat}$.

The resulting calculations in **Tables D2** and **D3** were adjusted using professional judgment regarding the applicability of point measurements – in time for hydraulic gradient and in space for hydraulic conductivity – to spatially distributed parameters. These adjusted fluxes are shown in the body of the present report in **Figure 52** and **Figure 53**. Detailed boundary flux calibration statistics are contained in **Table D1**. **Graphs D1** and **D2** present the calibration data, together with the upper and lower bounds for estimated flows. For 16 boundary segments, the groundwater flux predicted by the model lies within the expected bounds, while for four boundary segments the flow is outside the expected bounds.

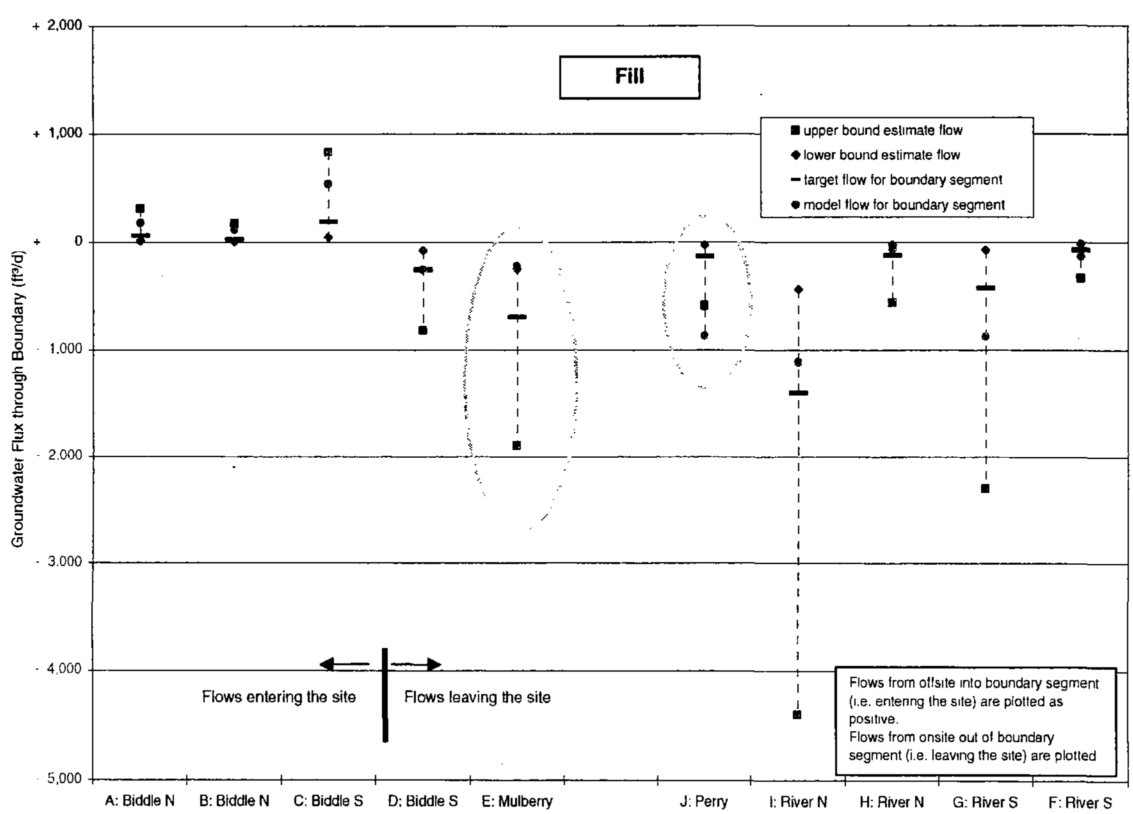
Table D1. Calibration Statistics by Boundary Segment

	Zone Budget Zone	Layers	Boundary Segment	Description	Calibration Target (Q_{target})	Model Flow (Q_{model})	residual (Q_{model} - Q_{target})	within bounds?
FILL	2	1	A	Biddle N	+ 61	+ 175	+ 114	yes
	3	1	B	Biddle N	+ 24	+ 113	+ 88	yes
	4	1	C	Biddle S	+ 186	+ 530	+ 344	yes
	5	1	D	Biddle S	- 259	- 260	- 0	yes
	6	1	E	Mulberry	- 800	- 228	+ 573	no
	7	1	F	River S	- 74	- 139	- 65	yes
	8	1	G	River S	- 422	- 875	- 453	yes
	9	1	H	River N	- 125	- 68	+ 57	yes
	10	1	I	River N	- 1,400	- 1,108	+ 292	yes
	11	1	J	Perry	- 93	- 872	- 779	no
						$\lvert R_{Q,FILL}\rvert_{AVG}$ =	314	ft³/d
NATIVE SAND	12	2,3	A	Biddle N	+ 635	+ 416	- 218	yes
	13	2,3	B	Biddle N	+ 109	+ 192	+ 83	yes
	14	2,3	C	Biddle S	+ 134	+ 148	+ 14	yes
	15	2,3	D	Biddle S	- 22	- 57	- 35	yes
	16	2,3	E	Mulberry	- 178	- 70	- 108	yes
	17	3	F	River S	- 4	- 46	- 42	no
	18	3	G	River S	- 476	- 378	+ 99	yes
	19	3	H	River N	- 127	- 40	+ 87	yes
	20	3	I	River N	- 118	- 375	- 256	yes
	21	3	J	Perry	- 462	- 401	+ 61	yes
						$\lvert R_{Q,NS}\rvert_{AVG}$ =	100	ft³/d
	1	all	n/a	rest of model	n/a	+13,469		
	22	2	E-J	Peat	n/a	+ 253		

SUMMARY STATISTICS	
$\Phi_Q = SSR_Q$ =	1,711,236 ft³/d
RMS_Q =	293 ft³/d
$\lvert R_Q \rvert_{AVG}$ =	207 [ft³/d]
$R_{Q,AVG}$ =	+ 20 ft³/d
normalized $\lvert R_Q \rvert_{AVG}$ =	96%



Graph D1. Flux Calibration for Native Sand



Graph D2. Flux Calibration for Fill

Table D2. Boundary Flux Calculations for the Native Sand Unit

NATIVE SAND

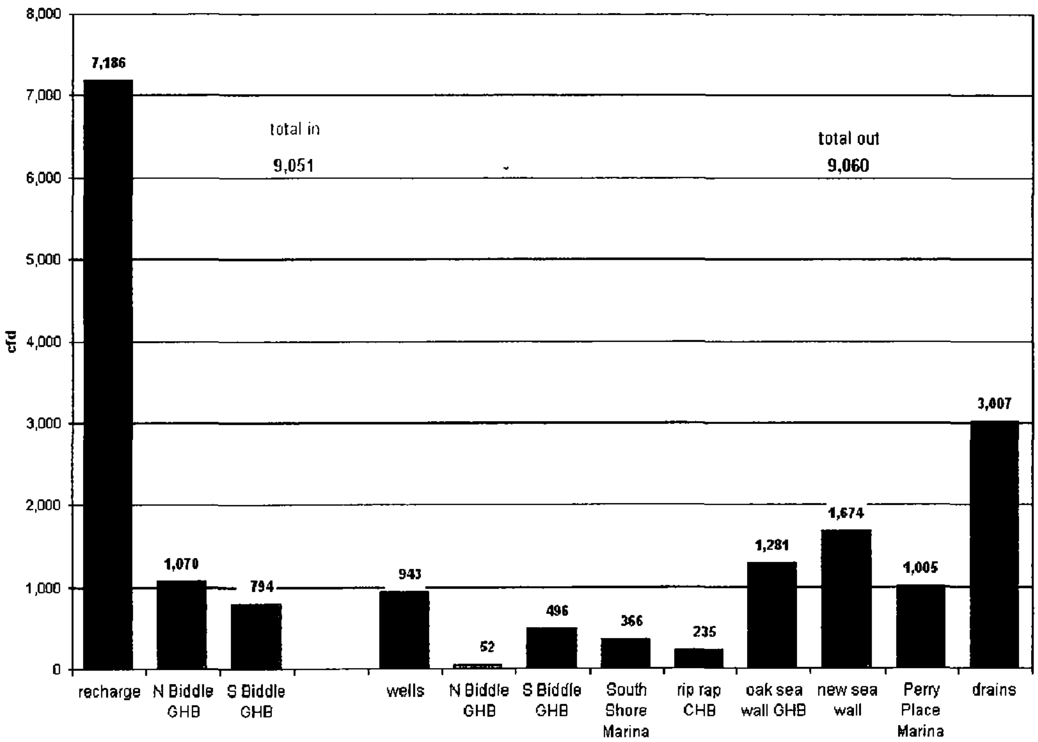
segment	location	hydraulic gradient	direction of hyd. grad.	perpendicular component of hyd. grad	length of boundary	saturated thickness	hydraulic conductivity	transmissivity	on-site flow for segment	off-site flow for segment	net on-site flow for segment
						boreholes	*slug tests*	$K \cdot b_{sat}$	$KiA = K \cdot (i \cdot comp.in) \cdot (s \cdot b)$		$\Sigma \Delta Q+ - \Sigma \Delta Q-$
		i	θ	comp.in	s	b_{sat}	K	T	$\Sigma \Delta Q+$	$\Sigma \Delta Q-$	$\Sigma \Delta Q$
		m/m	*degrees*	–	*ft*	*ft*	*ft/d*	*ft²/d*	*ft³/d*	*ft³/d*	*ft³/d*
A	Biddle N	0.009	100	+ 89%	1,198	5.1	7.2	36	289	0	+ 289
B	Biddle N	0.003	76	+ 96%	1,279	2.5	23.9	54	165	0	+ 165
C	Biddle S	0.003	68	+ 81%	1,644	1.1	14.2	25	121	0	+ 121
D	Biddle S	0.003	- 39	- 16%	967	2.1	1.5	3	0	8	- 7
E	Mulberry	0.006	- 22	- 56%	1,213	7.6	1.4	13	5	62	- 57
J	Perry	0.010	149	- 81%	930	6.	6.5	36	0	300	- 300
I	River N	0.007	133	- 94%	2,774	3.	1.5	4	0	77	- 77
H	River N	0.012	87	- 99%	694	9.	6.2	62	0	497	- 497
G	River S	0.009	82	- 99%	1,402	13.8	12.7	201	0	2,864	- 2,864
F	River S	0.004	- 53	- 29%	850	2.7	0.2	0	0	1	- 1
total for NATIVE SAND					**12,951**	**5.3**	**8**	**43**	**581**	**3,809**	**- 3,229**

Table D3. Boundary Flux Calculations for the Fill Unit

FILL

segment	location	hydraulic gradient	direction of hyd. grad.	perpendicular component of hyd. grad	incremental length	*boreholes* saturated thickness	*slug tests* hydraulic conductivity	transmissivity	on-site flow for segment	off-site flow for segment	net on-site flow for segment
		i	θ	comp.in	s	b_{sat}	K	T	Σ ΔQ	Σ ΔQ	Σ ΔQ
		m/m	*degrees*	–	*ft*	*ft*	*ft/d*	*ft²/d*	*ft³/d*	*ft³/d*	*ft³/d*
A	Biddle N	0.009	100	+ 89%	1,198	1.7	10.4	8	64	0	+ 64
B	Biddle N	0.003	76	+ 96%	1,279	1.2	2.3	3	8	0	+ 8
C	Biddle S	0.003	53	+ 63%	1,644	4.5	21.8	106	182	0	+ 182
D	Biddle S	0.003	- 61	- 58%	967	3.3	107.3	357	0	440	- 440
E	Mulberry	0.005	- 17	- 52%	1,213	4.	73.4	248	104	1,032	- 928
J	Perry	0.006	148	- 81%	930	4.	27.8	36	0	164	- 164
I	River N	0.013	127	- 97%	2,774	8.5	8.7	83	0	3,843	- 3,843
H	River N	0.011	89	- 99%	694	7.3	12.3	90	0	688	- 688
G	River S	0.011	66	- 78%	1,402	7.5	6.7	52	0	520	- 520
F	River S	0.007	68	- 86%	850	8.5	0.7	6	0	24	- 24
total for FILL					**12,951**	**5.**	**27**	**99**	**357**	**6,711**	**- 6,354**

Graph D3 provides a breakdown on the groundwater balance for the model domain as a whole. [Note that the model domain covers approximately 290 acres, of which the site represents only 231 acres].



Graph D3. Predicted Flows into and out of the Model Domain

Appendix E

Glossary of Site-Specific and Selected Technical Terms

Glossary of Site-Specific and Selected Technical Terms

Term	Definition	Source
aquifer	Rocks or unconsolidated sediments that are capable of yielding a significant amount of water to a well or a spring	1
	(1) A geologic formation, a group of formations, or a part of a formation that is water bearing (2) A geological formation or structure that stores or transmits water, or both, such as to wells and springs (3) An underground layer of porous rock, sand, or gravel containing large amounts of water. Use of the term is usually restricted to those water-bearing structures capable of yielding water in sufficient quantity to constitute a usable supply (4) A sand, gravel, or rock formation capable of storing or conveying water below the surface of the land (5) A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs	2
aquitard	Geologic formation(s) of low hydraulic conductivity, typically saturated, that yield a limited amount of water to wells	1
bedrock	A general term referring to rock that underlies unconsolidated material.	1
bias, biasing	A systematic difference between the true and measured value	1
borehole log (well log)	A record describing geologic formations and well testing or development techniques used during well construction or borehole drilling. Often refers to a geophysical well log in which the physical properties of the formations are measured by geophysical tools (e.g., E-logs and neutron logs)	1
boundary conditions	A mathematical model must be defined within a physical domain; the idealized flow or transport behavior along the domain boundaries form the boundary conditions of the model	1
calibration	The process of matching a model simulation with observed data. Typically, one or more model parameters are varied within reasonable limits until a suitable match is obtained	1
	The process by which the independent variables (parameters) of a numerical model are adjusted, within realistic limits, to produce the best match between simulated and observed data (usually water-level values). This process involves refining the model representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve the desired degree of correspondence between the model simulations and observations of the groundwater flow system.	3
capture zone	That portion of the groundwater flow system where the action of a pumping well causes the groundwater to flow to or be captured by that well	1
conceptual model	Our idealization of a hydrogeological system on which we can base a mathematical model. The conceptual model includes: assumptions on the hydrostratigraphy, material properties, dimensionality, and governing processes	1
	A simplified and idealized representation (usually graphical) of the physical hydrogeologic setting and our hydrogeological understanding of the essential flow processes of the system. This includes the identification and description of the geologic and hydrologic framework, media type, hydraulic properties, sources and sinks, and important aquifer flow and surface-groundwater interaction processes.	3
conductance	MODFLOW: conductance is a measure of the degree of hydraulic connection between elements in a groundwater flow model, e.g. between adjacent model cells or between a drain and the model cell that contains the drain. Used for drains, rivers, general head boundaries. Conductance = hydraulic conductivity × flow area / flow length $C = K \cdot A/L\ [L^2/T]$	*
confining layer	A geologic body of low hydraulic conductivity above or below one or more aquifers. Also called an aquitard	1
connectivity	The degree to which a hydraulic connection exists between different parts of a conceptual or numerical hydrogeological model	1
constant head boundary (CH)	MODFLOW: a cell whose hydraulic head is specified outside of the model rather than calculated by the model. Also called 1st type or Dirichlet boundary condition. Head may vary with time.	*

Term	Definition	Source
Darcy's Law / equation	An empirical law that states that flow velocity through a porous medium is directly proportional to the hydraulic gradient (assuming there is laminar flow and negligible inertia). $q = Ki$, where q = groundwater flux (flow per unit area) (L^3/T / L^2 or L/T, eg. m/d) K = hydraulic conductivity (L/T, e.g. m/d) i = hydraulic gradient (L/L, e.g. m/m)	1
discharge	The rate of flow at a given time, measured as volume per unit time	1
distiller blow-off (DBO)	A fine-grained waste byproduct of the Solvay Process for crude sodium bicarbonate production, consisting of a mixture of sodium carbonate, calcium chloride, sodium chloride, calcium sulfate, sodium sulfate, and some excess lime. DBO is a white, putty-like substance with low permeability.	*
domain	In modeling, the segment of the subsurface being considered. It is defined by its boundaries and interior geometry (based on its hydrostratigraphy), and its material properties (e.g., porosity and hydraulic conductivity).	1
drain	MODFLOW: Groundwater infiltration into drains is calculated in MODFLOW using a formula similar to that for head dependent flux boundaries: $Q_{DRN} = (H - H_{REF}) \cdot C_{DRN}$ for $H > H_{REF}$ $Q_{DRN} = 0$ for $H \leq H_{REF}$ where: Q_{DRN} = groundwater flow (ft³/d) (+ve → flow from boundary into model; −ve → flow out of model into boundary) H = hydraulic head in area (model cell) that contains the drain (ft above elevation datum) H_{REF} = elevation of water surface in drain (ft above elevation datum) C_{DRN} = drain conductance (ft²/d) – as conductance increases, the drain collects more water.	*
dry cell	MODFLOW: a model cell in which the calculated hydraulic head is below the bottom elevation of the cell – the cell is treated as inactive (no flow), but may be wetted at a later time in a transient simulation	*
effective porosity	The amount of interconnected pore space through which fluids can pass. Effective porosity is usually less than total porosity because some dead-end pores may be occupied by static fluid	1
equilibrium	Condition that exists in a system when the system does not undergo any change of properties over time; usually multiple forces produce a steady balance, resulting in no change over time	1
fidelity	The degree to which a model application resembles, or is designed to resemble, the physical hydrogeological system (Ritchey and Rumbaugh, 1996). The ASTM guides apply a hierarchical classification of three main fidelities in order of increasing fidelity: Screening, Engineering Calculation and Aquifer Simulator. Higher fidelity models have a capability to provide for more complex simulations of hydrogeological process and/or address resource management issues more comprehensively. The term ***complexity*** is sometimes used in place of fidelity.	3
flow lines	Flow lines indicate the direction of groundwater flow toward points of discharge. They are perpendicular to equipotential lines in homogeneous media. Also known as streamlines	1
General Head Boundary (GHB)	MODFLOW: Head dependent flux boundaries are termed "general head boundaries" (GHB) in MODFLOW. These differ from constant head boundaries in that flow to or from them is controlled by an estimate of hydraulic conductance, i.e. $Q_{GHB} = (H_{REF} - H) \cdot C_{GHB}$ where: Q_{GHB} = groundwater flow (ft³/d) (+ve → flow from boundary into model; −ve → flow out of model into boundary) H_{REF} = reference hydraulic head for boundary, e.g. river level (ft above elevation datum) H = hydraulic head in area (model cell) that contains the boundary (ft above elevation datum) C_{GHB} = boundary conductance (ft²/d) – as conductance increases, the boundary approaches a constant head boundary; as conductance approaches zero, the boundary approaches a no-flow boundary.	*

Term	Definition	Source
geographical information system (GIS)	A computer software system with which spatial information may be captured, stored, analyzed, displayed, and retrieved	2
groundwater divide	The rather vague division between groundwater basins. When the divide meets the land surface, water on one side of the divide will flow into one groundwater system; whereas, water recharging on the other side of the divide will flow into another groundwater system or basin. Somewhat analogous to surface water basins and divides	1
head dependent flux boundaries	Also called 3rd type or Cauchy boundary condition – see "general head boundary"	*
heterogeneous	Composed of non-uniform constituents whose material properties vary in space. All geological material is heterogeneous, but the property of interest (e.g., porosity) may be sufficiently uniform for the material to be treated as homogeneous in terms of that property	1
homogeneous	Composed of uniform constituents throughout. That is, having material properties (e.g., hydraulic conductivity) that do not vary in space.	1
hydraulic conductivity (K)	A coefficient of proportionality that describes the ease with which a fluid can move through a porous medium. It is a function of both the medium and of fluid flowing through the medium	1
	A coefficient of proportionality describing the rate at which water can move through an aquifer or other permeable medium. In the Standard International System, the units are cubic meters per day per square meter of medium ($m^3/day/m^2$) or m/d. Other common units are meters per second (m/s), centimeters per second (cm/s) or feet per day (ft/d). See also: Darcy's Law	2
hydraulic gradient (i)	The ratio of the change in total head to distance in a given direction. In an unconfined unit, the hydraulic gradient is the slope of the water table. In any geological unit (including confined aquifers), it is the slope of the potentiometric surface. Measured in units of L/L, eg. m/m or ft/ft, and is often reported as dimensionless (–). See also: Darcy's Law	1
hydraulic head	The height to which water can raise itself above an arbitrary datum level. Commonly measured in an observation well. Measured in units of L, e.g. meters or feet.	1
hydrogeologi-cal model	A representation, often simplified and perhaps conceptual, of the hydrogeological flow system. The aspects important for the site are emphasized. See also model	1
hydrology	The science of earth's water resources. The scope of hydrology includes water's occurrence, distribution, circulation, physical and chemical properties, and reactions with and effects on the environment	2
hydrostrati-graphic unit	A formation, part of a formation, or a group of formations that have similar hydrogeologic characteristics	1
hydrostrati-graphy	The study of stratigraphic sequence of unconsolidated materials and rock strata (layers), dealing specifically with their form, distribution, and ***hydrogeologic*** properties.	*
impermeable	A material that does not easily transmit a fluid. It is often defined arbitrarily and in relation to more permeable materials present in the same area. For example, a shale may be impermeable relative to a nearby sandstone. An impermeable boundary is assumed to be the edge of impermeable material	1
in situ	Referring to conditions or processes that occur in the natural or original location. For soils and groundwater, this means underground, without excavation or pumping to the surface. Compare *ex situ*	*
infiltration	The flow of water downward from the land surface into and through soil and rock pores	1
infiltration/infl ow	Groundwater or storm water flow into a sanitary sewer system through cracked pipes or improper connections	2
isopach	A line drawn on a map through points of equal thickness of a designated stratigraphic unit or group of stratigraphic units	*
lacustrine	Formed in, produced by, or pertaining to a lake	1
lens	A geologic deposit surrounded by converging surfaces; therefore, it is thick in the middle and thins out towards the edges	1

Term	Definition	Source
mass flux	Like fluid flux, but the mass of a chemical dissolved in groundwater that moves through a specified cross-sectional area per unit time	1
MODFLOW	A modular three-dimensional finite difference groundwater flow code developed by the USGS. The current report uses the MODFLOW 2000 version (Harbaugh et al., 2000)	*
model	A conceptual, mathematical, or physical system intended to represent a real system. The behavior of a model is used to understand processes in the physical system to which it is analogous	1
no flow boundary	A specific example of a 2nd type (Neuman) boundary where $q = 0$ i.e. the boundary is impermeable	*
non-unique	In geological interpretation and mathematical modeling, a problem for which two or more subsurface models satisfy the data equally well.	1
non-uniqueness	The principle that many different possible sets of model inputs can produce nearly identical computed aquifer head distributions for any given model.	3
	Because flow $Q = -K\,i$ (see Darcy's Law), combinations of Q and K which yield the same ratio of Q/K will produce similar hydraulic gradients i, and so similar head distributions.	*
numerical model	A model of groundwater flow in which the aquifer is described by numerical equations, with specified values for boundary conditions, that are usually solved on a digital computer. In this approach, the continuous differential terms in the governing hydraulic flow equation are replaced by finite quantities. The computational power of the computer is used to solve the resulting algebraic equations by matrix arithmetic. In this way, problems with complex geometry, dynamic response effects and spatial and temporal variability may be solved accurately. This approach must be used in cases where the essential aquifer features form a complex system, and where surface-groundwater interaction is an important component (ie. high complexity models).	3
peat	An unconsolidated deposit of partially decomposed plant matter with high moisture content, in a water-saturated environment	1
piezometer	A non-pumping well that is used to measure the elevation of the water table or potentiometric surface. It can be used to measure head at a point in the subsurface	1
porosity	The ratio of the volume of pore spaces in a rock or sediment to the total volume of the rock or sediment. Measured in units of L^3/L^3, eg. cm^3/cm^3 or in^3/in^3, and is thus often reported as dimensionless (–)	1
potentiometric map	A map that shows through contour lines or other symbols, the potentiometric surface elevation (hydraulic head) of an aquifer	1
precision	The reproducibility of a measurement: the closeness of each of a set of similar measurements to the arithmetic mean of that set	1
recharge (Rch)	Addition of water to the groundwater system by natural or artificial processes	1
	The addition of water to the groundwater system by natural (precipitation and infiltration) or artificial processes (Rch = P – RO – ET)	2
	MODFLOW: A specific example of a 2nd type (Neuman) boundary where $q = q(t)$ [L/T] applied on an areal basis to the uppermost active model cell in a column	*
remediation	The clean up of contaminated soil or groundwater	1
runoff (RO)	Rainwater that does not infiltrate the soil but flows across the earth's surface into a body of water. The proportion of rainwater that penetrates the soil varies considerably depending on soil type and area covered by impervious materials. Runoff has the potential to "carry" contaminants resting on the earth's surface	2
saturated zone	The zone where voids in the soil or rock are filled with water at greater than atmospheric pressure. In an unconfined aquifer, the water table forms the upper boundary of the saturated zone	1
sensitivity analysis	After a model is calibrated, a sensitivity analysis is often completed to address the sensitivity of the simulation to specific input parameters. A sensitivity analysis is useful to determine additional field data requirements and to identify non-uniqueness	1
site	property at 1609 Biddle Street, Wyandotte, Michigan currently owned and operated by BASF Corporation, subject of the present report	*

Term	Definition	Source
slug test	A test carried out to determine *in situ* hydraulic conductivity by instantaneously adding a known water quantity (or solid cylindrical object of know displacement) to a well, and measuring the resulting well recovery. Used for single wells in low to moderate hydraulic conductivity formations. Also called falling head test	1
specific storage (S_S)	The quantity of water released from or taken into storage per unit volume of a porous medium, per unit change in head	1
specific yield (S_Y)	The ratio of the volume of yield of water by gravity drainage from a rock or solid (after being saturated), to the volume of the rock or soil	1
specified flux boundary	Also called a 2nd type or Neuman boundary condition. $q = q(t)$ (eg. impermeable boundary; wells; recharge)	*
specified head boundary	see "constant head boundary"	*
steady state	The state of a system whereby conditions at each point do not change with time	1
storativity (S)	The volume of water released from or taken into storage per unit surface area of aquifer, per unit change in head. Also know as storage coefficient	1
stratigraphy	The study of succession (stratigraphic sequence) and age of unconsolidated materials and rock strata (layers), dealing with their form, distribution, lithologic composition, fossil content, and geophysical and geochemical properties. Compare hydrostratigraphy	1
surface water	The portion of water that appears on the land surface (e.g., oceans, lakes, and rivers)	1
transient	Occurring when the system is still changing with time (i.e., a steady state has not been attained). Most groundwater flow systems are transient, not steady state	1
transmissivity	The rate at which water of a certain density and viscosity is transmitted under a unit hydraulic gradient through a unit width of an aquifer (or confining bed). Transmissivity depends on properties of the liquid and porous medium. Also known as the coefficient of transmissibility	1
	The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Measured in units of L^2/T, e.g. m^2/d or ft^2/d.	2
uncertainty	The estimated quantity by which an observed or calculated value may depart from the true value	1
unconfined aquifer	An aquifer that has a water table and is not bounded by an overlying layer of distinctly lower permeability	1
unit	Any geologic layer present at various points of interest at a site, generally continuous over at least a portion of the study area, e.g. a layer of sand or a layer of clay. Units may be homogeneous or heterogeneous.	*
unsaturated zone	The area between the ground surface and the water table, including the root zone, intermediate zone, and capillary fringe. Pore spaces contain water at less than atmospheric pressure, as well as air and other gasses. Also known as vadose zone or zone of aeration	1
utility corridor / trenches	A subsurface trench in which pipes or electrical lines are place. It is usually filled with coarse material and therefore may be much more permeable than the surrounding material	1
validation	Before a mathematical model can be accepted for use, it must be validated, or proven to realistically simulate the processes for which it was designed. Validation is usually completed by comparing model results with a controlled laboratory or field-scale experiment	1
verification	A mathematical model is verified by comparing the results with a known exact solution, often obtained using an analytical model	1
water budget	A water budget is general model of the complete hydrological cycle. For this study, the water budget provides estimates of ; the quantity of water cycling through the study area (average annual precipitation); the quantity of water returned to the atmosphere by evapotranspiration, the quantity of water that contributes to groundwater resources	2
water table	The upper limit of the saturated zone. It is measure by installing wells that extend a few feet into the saturated zone and then recording the water level in those wells	1
	The level of groundwater saturation. The depth of the water table is determined by the quantity of groundwater and the permeability of the earth material and fluctuates accordingly. The water table is often the upper surface of an unconfined aquifer	2

Sources:

1 Subsurface Assessment Handbook for Contaminated Sites, Report CCME EPC-NCSRP-48E, March 1994
2 Eastern Ontario Water Resources Management Draft Final Report, December 2000
3 Groundwater Flow Modelling Guideline, November 2000, Aquaterra Consulting Pty Ltd
* defined for the purposes of the present report

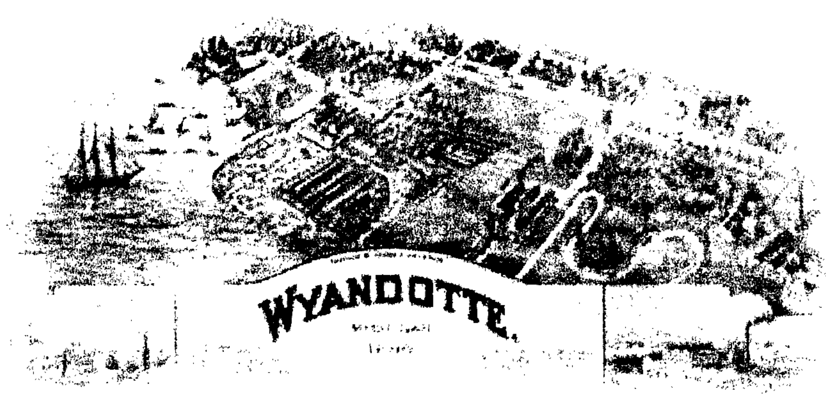
List of Abbreviations and Acronyms

amsl	above mean sea level
cfd	cubic feet per day (ft^3/d)
CMS	Corrective Measures Study
d	abbreviation for day (24 hours)
DBO	distiller blow-off (a waste material)
ft	abbreviation for: foot (0.3048 m)
ft^2	abbreviation for: square foot (1 acre = 43560 ft^2)
ft^3	abbreviation for: cubic foot (28.3 liters, or 7.48 US gallons)
GIS	Geographic Information System
gpm	abbreviation for: US gallon per minute (5.45 m^3/d, 192.5 ft^3/d)
HELP	Hydrologic Evaluation of Landfill Performance – an infiltration model
IGLD 1985	International Great Lakes Datum of 1985 – the elevation reference system used to define water levels in the current report (IGLD 1985 = IGLD 1955 + 0.64 ft)
m	abbreviation for: meter (3.28 ft)
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
MODFLOW	U.S. Geological Survey modular ground-water model
OMOE	Ontario Ministry of the Environment
POTW	Publicly Owned Treatment Works – e.g. municipal sewage treatment plant
RCRA	Resource Conservation and Recover Act
RFI	RCRA Facility Investigation
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WHI	Waterloo Hydrogeologic, Inc., author of the present report

BASF WYANDOTTE NORTH WORKS

Corrective Measures Study
Groundwater Modeling

FIELD INVESTIGATION REPORT



June 2002

Report by:

waterloo
hydrogeologic
SOFTWARE · CONSULTING · TRAINING

Report for:

BASF

BASF
The Chemical Company

Helping Make Products Better™

May 22, 2006

Mr. Juan Thomas
Project Manager
United States Environmental Protection Agency
Region V (DE-9J)
77 West Jackson Street
Chicago, Illinois 60604

Subject: Field Investigation Report
BASF Corporation, North Works Property

Dear Mr. Thomas:

In response to your inquiry on May 19, 2006, I am providing the Environmental Protection Agency with a copy of the Field Investigation Report prepared for BASF Corporation by Waterloo Hydrogeologic. The Report discusses installation and development of 37 new piezometers during early 2002 to supplement the groundwater modeling network then currently in place. Please find the borehole logs and well installation details in Appendix B.

I also enclosed a color copy of the drawing transmitted via facsimile on May 15, 2006. The enclosed copy should be easier to read.

Should you have any questions, please do not hesitate to call me at 734-324-6219. My e-mail address is jack.lanigan@partners.basf.com.

Sincerely,

Jack Lanigan
Consulting Geologist

Enclosures

BASF Corporation
1609 Biddle Avenue
Wyandotte, MI 48192-3729
Tel: (734) 324-6000
www.basf.com/usa

Field Investigation Report
BASF Corporation
North Works Facility
1609 Biddle Avenue
Wyandotte, Michigan

SYNOPSIS

Start Date: 28 January 2002
End Date: 08 February 2002

Piezometers Installed: 37
Wells Monitored: 37(new) + 80(existing) = 117

28 Jan set up drilling locations
29 Jan 6 borehole logs, 6 piezometers
30 Jan 5 borehole logs, 4 piezometers
31 Jan field work cancelled due to freezing rain
01 Feb 4 borehole logs, 6 piezometers
04 Feb 3 borehole logs, 5 piezometers
05 Feb 4 borehole logs, 4 piezometers, 2½ h down time
06 Feb 5 borehole logs, 7 piezometers
07 Feb 3 borehole logs, 4 piezometers, ½ day drilling
meeting with BASF re Preliminary Modeling Results
water level monitoring
08 Feb water level monitoring

Companies:

Client:	BASF Corporation, Wyandotte, Michigan
Consultant:	Waterloo Hydrogeologic Inc., Waterloo, Ontario (WHI)
Driller:	Fibertec Environmental Services, Wixom, Michigan
Surveyor:	Urban Engineering Company

Personnel:

BASF:	Bruce D. Roberts, Senior Environmental Specialist, Client Contact
	Pete Greer, Plant Engineering
	Joe Gavlinsky, Plant Engineering
WHI:	David R. Tamblyn, Environmental Engineer, Field Supervisor
Fibertec:	Mike McCourtnie, Environmental Scientist, Driller
	Fred Myall, Drilling Assistant
	Burton Weiss, Drilling Assistant

Contact Information:

Bruce:	(734) 324-6298, robertb@basf.com
Pete:	(734) 324-6168
Joe:	(734) 324-6720
Dave:	(519) 746-1798 x232, dtamblyn@flowpath.com
Mike:	(800) 686-0345

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1.0 OBJECTIVES

In a letter to Mr. Bruce Roberts dated 22 January 2002 (Request for Change Order for PO# 30371205, BASF North Works Facility Groundwater Flow Model), WHI identified five key areas of uncertainty to be resolved through additional field investigations:

1. groundwater flow direction in Fill and Native Sand along boundaries
2. groundwater flow direction in Fill and Native Sand along seawall in northern part of site
3. hydraulic influence of former shipyard channel in south eastern part of site
4. water levels and stratigraphy along western boundary (Biddle)
5. apparently anomalous water levels in certain wells.

2.0 METHODOLOGY

Methodologies included borehole drilling and piezometer installation, topographical surveying, and water level monitoring in existing wells, using the following:

- Direct Push coring
- GPS horizontal control survey of new boreholes and anomalous existing monitoring wells
- Vertical control survey of Direct Push locations and anomalous existing monitoring wells
- Partial water level survey of existing wells.

2.1. Borehole Drilling

Direct Push coring was performed using a Geoprobe™ 66DT track-mounted percussion probing machine using the Dual Tube Sampling System (DTSS) with a GH60 hammer, 3.25 inch probe rods, and the DT32 Sampler to retrieve 2 inch diameter by 5 foot length samples. This methodology is dry, i.e. no drilling fluids are required, and produces good quality continuous soil samples. Recovery percentage is typically much better than with a split-spoon sampler.

Limitations of the Geoprobe system include:

- limited ability to penetrate concrete
- probe tip can be deflected off-vertical by stones, cobbles, concrete chunks, etc.
- sampling tip may be blocked with stones, cobbles, etc., which prevents sample recovery
- retractive force limits maximum penetration depth, especially in cohesive soils.

Additional details of the Direct Push coring system are contained in **Appendix A.**

Sample cores were inspected by WHI and the observations noted in field stratigraphy logs. **Figure 1** illustrates drilling and sample inspection. **Figure 2** shows a typical field log. Computer-generated logs documenting overburden stratigraphy and well construction are presented in **Appendix B.**

Soil samples were disposed of on the grounds of the subject property (1609 Biddle Avenue). Soil sample tubes were disposed of in appropriate waste bins on the subject property.

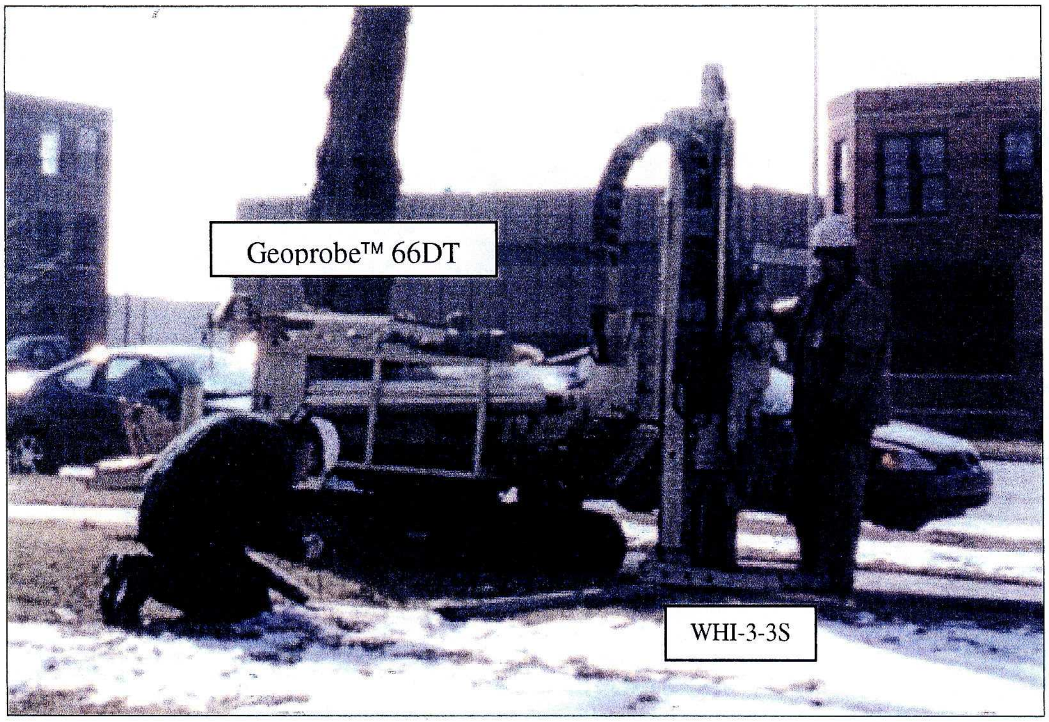
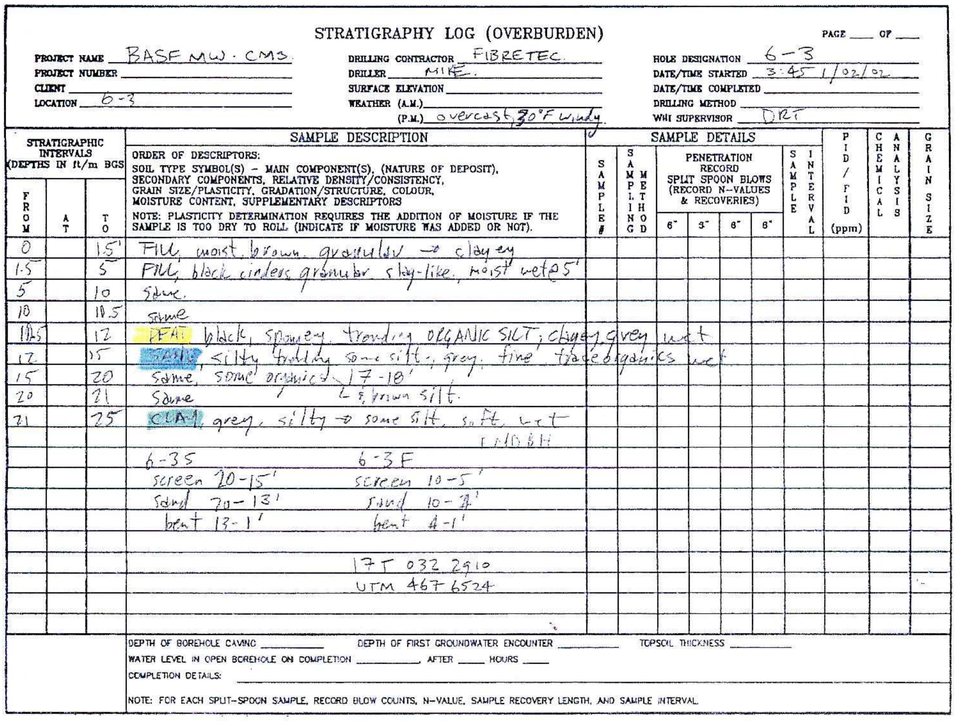


Figure 1. Borehole Drilling and Sample Core Inspection



STRATIGRAPHY LOG (OVERBURDEN)

PAGE ___ OF ___

PROJECT NAME BASF MW · CMS
PROJECT NUMBER
CLIENT
LOCATION 6-3

DRILLING CONTRACTOR FIBRETEC.
DRILLER MIKE.
SURFACE ELEVATION
WEATHER (A.M.)
(P.M.) overcast, 30°F windy.

HOLE DESIGNATION 6-3
DATE/TIME STARTED 3:45 1/02/02
DATE/TIME COMPLETED
DRILLING METHOD
WHI SUPERVISOR DRT

STRATIGRAPHIC INTERVALS (DEPTHS IN ft/m BGS) FROM	AT	TO	SAMPLE DESCRIPTION — ORDER OF DESCRIPTORS: SOIL TYPE SYMBOL(S) – MAIN COMPONENT(S), (NATURE OF DEPOSIT), SECONDARY COMPONENTS, RELATIVE DENSITY/CONSISTENCY, GRAIN SIZE/PLASTICITY, GRADATION/STRUCTURE, COLOUR, MOISTURE CONTENT, SUPPLEMENTARY DESCRIPTORS. NOTE: PLASTICITY DETERMINATION REQUIRES THE ADDITION OF MOISTURE IF THE SAMPLE IS TOO DRY TO ROLL (INDICATE IF MOISTURE WAS ADDED OR NOT).	SAMPLE #	SAMPLING METHOD	PENETRATION RECORD SPLIT SPOON BLOWS (RECORD N-VALUES & RECOVERIES) 6"	3"	6"	6"	SAMPLE INTERVAL	PID / FID (ppm)	CHEMICAL ANALYSIS	GRAIN SIZE
0		1.5'	FILL, moist, brown, granular → clayey										
1.5		5	FILL, black cinders granular slag-like, moist wet@5'										
5		10	same.										
10		10.5	same										
10.5		12	PEAT, black, spongey, trending ORGANIC SILT; clayey, grey, wet										
12		15	SAND, silty trending some silt, grey, fine, trace organics wet										
15		20	same, some organics, 17-18'										
20		21	same, brown silt.										
21		25	CLAY, grey, silty → some silt, soft, wet										
			END BH										
			6-3S 6-3F										
			screen 20-15' screen 10-5'										
			sand 20-13' sand 10-4'										
			bent 13-1' bent 4-1'										
			17T 032 2910										
			UTM 467 6524										

DEPTH OF BOREHOLE CAVING ______ DEPTH OF FIRST GROUNDWATER ENCOUNTER ______ TOPSOIL THICKNESS ______
WATER LEVEL IN OPEN BOREHOLE ON COMPLETION ______, AFTER ____ HOURS ____
COMPLETION DETAILS:
NOTE: FOR EACH SPLIT-SPOON SAMPLE, RECORD BLOW COUNTS, N-VALUE, SAMPLE RECOVERY LENGTH, AND SAMPLE INTERVAL.

Figure 2. Sample Field Stratigraphy Log

2.2. Piezometer Installation

All installed piezometers used 1 inch diameter, 0.010 inch slot PVC screen ("ten slot") with 1 inch diameter PVC riser. These are shown in **Figure 3** below. For most wells, a standard 5 foot screen section (actually 4.5 foot screened section with 0.25 feet unscreened at the top and bottom) was used. In very shallow wells, or where the target hydrogeologic unit was thin, the screen was cut to length and the bottom capped.

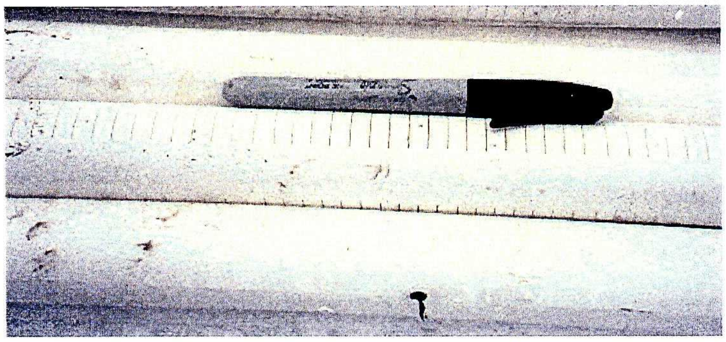


Figure 3. PVC Well Screen and Riser

In typical unconfined groundwater conditions, piezometers were installed in the same hole used for logging stratigraphy. The screen section was fitted to the riser, and placed down the borehole at the desired depth. Silica sand was poured from the surface to cover the screen. Granular bentonite was then poured from the surface to seal the screen from surface water.

Confined conditions require additional care to ensure the well screen is properly isolated from groundwater in upper strata. Pressure grouting is recommended when confined aquifer conditions force significant amounts of groundwater into the borehole. However, pressure grouting is very time consuming and is more difficult in winter conditions. Because of these limitations, pressure grouting was not used during the present field program. To install deep wells, the following procedure was adopted:

- the borehole was drilled and logged normally (groundwater enters borehole through open sampling hole at base of rods)
- if confined groundwater conditions existed, a separate borehole was drilled within a few feet of the first, using an expendable solid point (no sampling) to the desired depth of piezometer installation (small amounts of water may still enter the borehole through joints in the drive rods)
- the piezometer (PVC screen and riser), was installed in the (dry) borehole
- the filter pack material (silica sand) was poured from the surface at a slow rate to prevent bridging, and the drive rods gradually retracted until the sand was approximately 1 to 2 feet above the screened interval
- the annular seal material (granular bentonite) was poured from the surface at a slow rate to prevent bridging, and the drive rods gradually retracted until the bentonite was approximately 1 foot below ground surface.

Wells were finished with a 1 foot concrete section and a 7 inch diameter protective steel casing with cover secured by three hex bolts. The name of the piezometer (e.g. WHI-6-3) was inscribed on the metal plate on the outside of the protective steel casing. The top of the piezometer was covered with a slip cap or with an H-plug seal. The name of the piezometer was also written in black indelible marker on the H-plug. It is recommended that all piezometers be fitted with H-plug seals if future monitoring is to be carried out. The measurement point for water levels is the highest point on the 1 inch diameter PVC riser. This location was marked with a black indelible marker.

Typical flush-mount piezometer construction is shown in **Figure 4** below. **Figure 5** shows the protective steel casing with name plate.

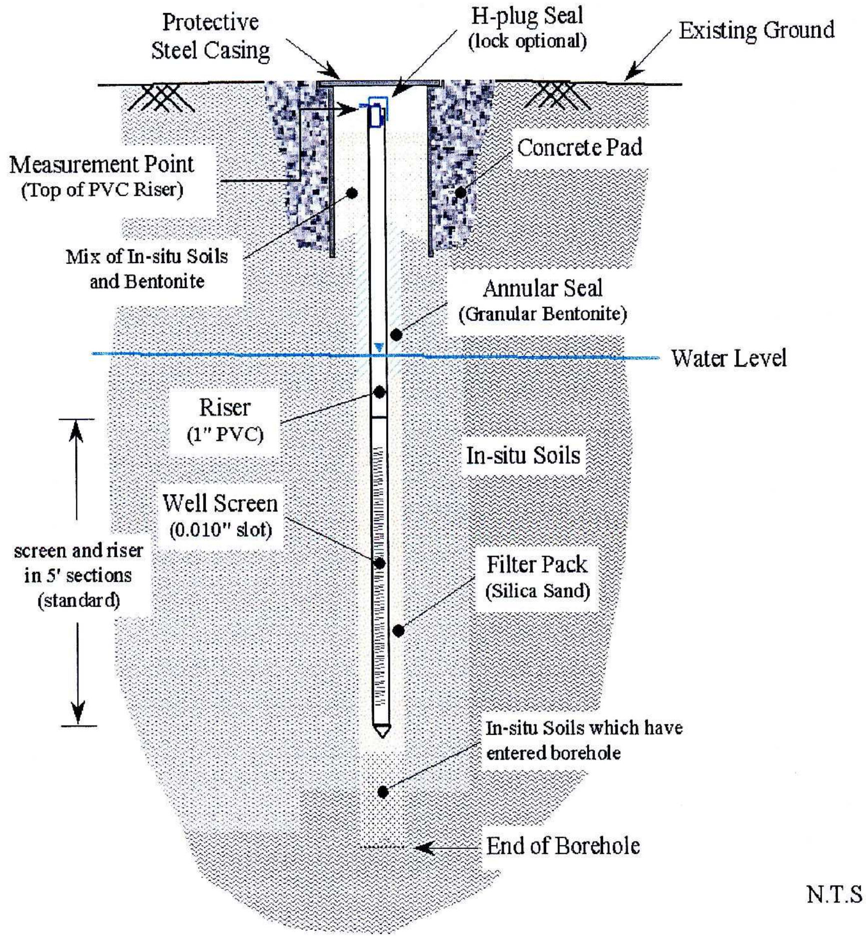


Figure 4. Typical Piezometer Construction

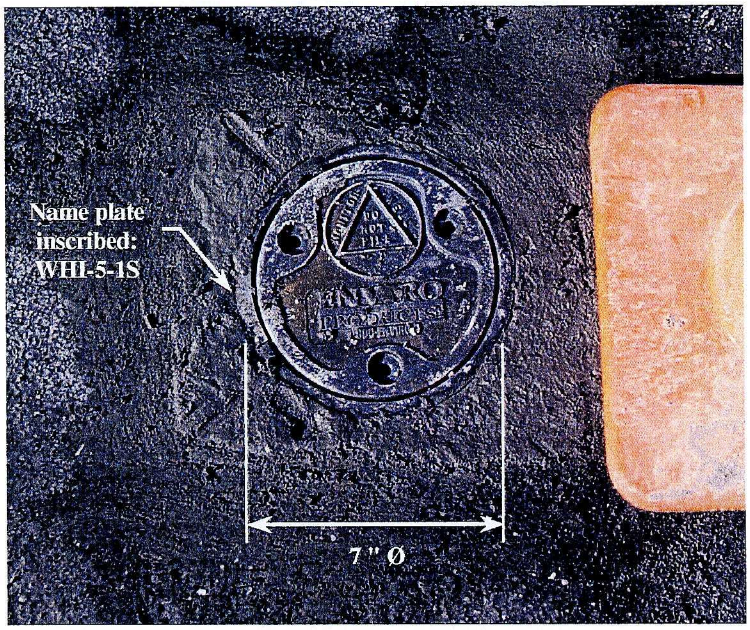


Figure 5. Typical Piezometer Cover

Piezometers were not developed. During monitoring, it was noted that silt had accumulated in some of the piezometers and it is recommended that this situation be evaluated when the piezometers are next monitored. If silt accumulation (as judged by depth to bottom of well) threatens to cover the screened interval, then corrective action, such as well development, may be necessary. Well development would also be necessary if slug tests were contemplated in the future.

Decontamination of the drilling equipment was carried out to keep the rods in good operating condition, but did not follow the protocol for the installation of monitoring wells for groundwater sampling. As such, the installed piezometers are not suitable for assessing groundwater quality.

2.3. Horizontal Control Survey

The location (Northing and Easting) of all new boreholes was recorded in UTM coordinates (NAD27 CONUS datum) at the time of drilling using a Garmin GPS 12XL. Control points were acquired during a previous site visit to allow a least-squares fit to estimate the relation between plant coordinates (origin on-site) and UTM coordinates. This information was very useful in positioning the proposed borehole locations. Existing monitoring wells were also stored as part of the monitoring, allowing for a check on well identification.

The precise horizontal control survey of new borehole locations and anomalous existing wells was undertaken by Urban Engineering Company during the month of March. The results are documented in letters to BASF dated 6 March, 25 March, and 8 April 2002. The coordinates are relative to the site coordinate and system grid as shown on BASF Site Ground Water System, Drawing No. 50403.

2.4. Vertical Control Survey

The vertical control survey of new borehole locations and anomalous existing wells was undertaken by Urban Engineering Company during the month of March. The results are documented in letters to BASF dated 6 March, 25 March, and 8 April 2002. The elevation data are relative to the International Great Lakes Datum 1985 (IGLD 1985) (benchmark = S.W. bolt on pipe rack base, north side of Alkali Street, first rack west of railroad tracks, elevation 579.66 ft above IGLD 1985).

2.5. Water Level Survey

The water level in existing wells and new piezometers was measured using a Solinst Model 101 Water Level Tape. Depth to bottom of well was also recorded to evaluate sedimentation of the wells and to provide an additional check (along with the GPS survey) on well identification. Water level monitoring is shown in **Figure 6**.

Figure 6. Water Level Monitoring

2.6. River Level Estimation

River levels were measured on two separate occasions at the South Wall - Perry Place and South Marina - Mulberry St. to establish the relation between water levels in the Detroit River at the site and those measured at National Oceanic & Atmospheric Administration (NOAA) Station Gibraltar (9044020) and Station Wyandotte (9044030). Station Wyandotte is located approximately 3250 ft south (downstream) of the southern end of the site. Station Gibraltar is located a further 42,250 ft downstream. The relation is shown in **Figure 7** below. Thus, mathematically, the Detroit River water level at a point adjacent to the North Works site is estimated as:

$$Z_{NW} = Z_{NOAA\ WYANDOTTE} + \mathbf{x} \cdot \text{slope} \pm \mathbf{\Delta z}$$

where
- Z_{NW} = average river level at a point adjacent to the North Works
- $Z_{NOAA\ WYANDOTTE}$ = average river level at NOAA Station Wyandotte
- $\mathbf{x}$ = distance upriver from NOAA Station Wyandotte
- slope = average river slope
- Δz = deviation from straight-line extrapolation based on measured river levels at site monitoring locations (Perry Place and South Marina).

The averaging period used is the 15 days prior to monitoring. Measurements at the NOAA stations are based on daily averages of 6 minute interval data, all referenced to IGLD 1985. All NOAA river level data were downloaded from official web sites:

- http://co-ops.nos.noaa.gov/data_retrieve.shtml?input_code=001011111pgl&station=9044020+Gibraltar,+MI
- http://co-ops.nos.noaa.gov/data_retrieve.shtml?input_code=001011111pgl&station=9044030+Wyandotte+MI

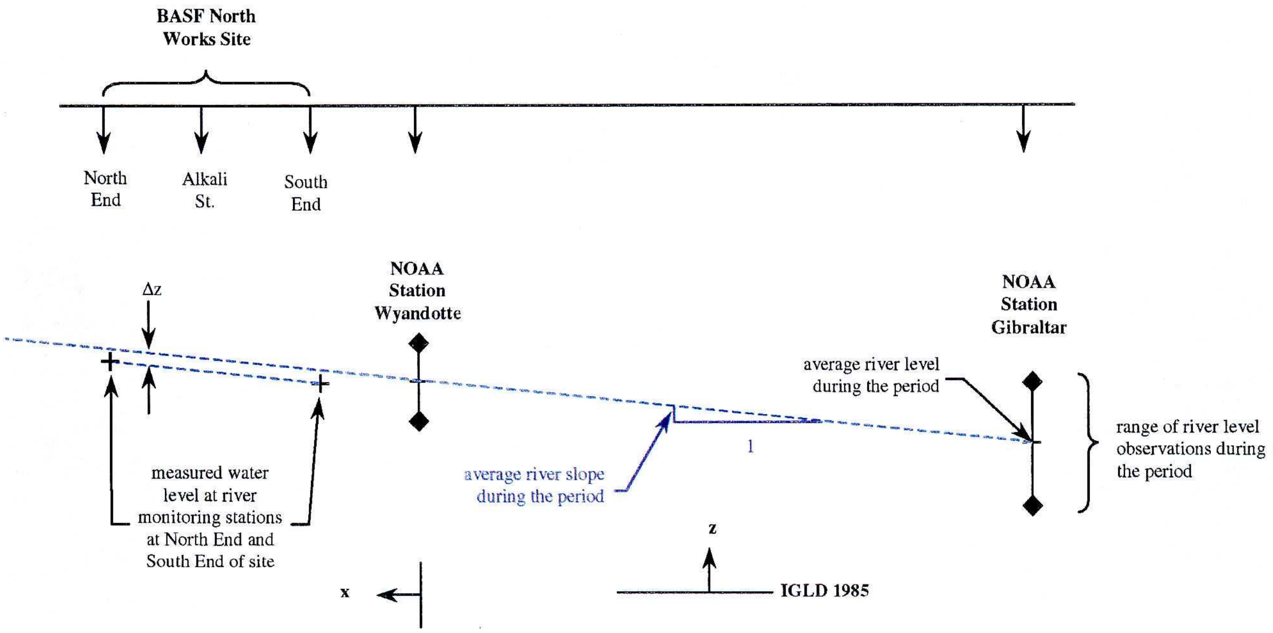
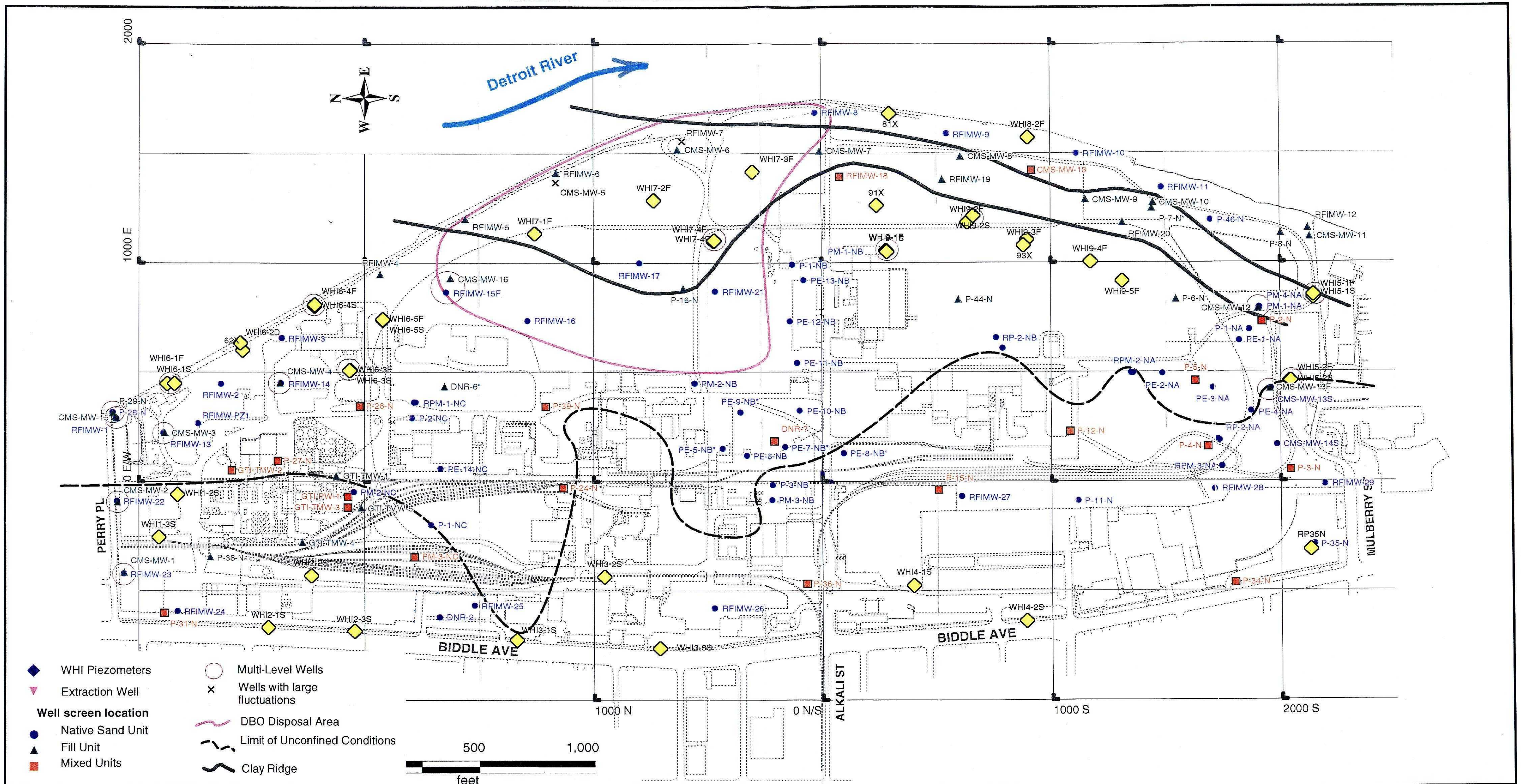


Figure 7. River Level Model

The location of new boreholes in relation to existing monitoring wells is shown on **Figure 8** below.



waterloo hydrogeologic
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BASF

Water Level Monitoring Well Locations

BASF-Wyandotte North Works

Figure 8

Field Investigation Report

June 2002

3.0 RESULTS

In all, 37 new water level monitoring locations were established, and one existing monitoring well was replaced. Detailed borehole logs are contained in **Appendix B**.

Table 1. Piezometer Installation Data in **Appendix C** details the locations and elevation data for the new boreholes, along with well construction details. Two new monitoring locations for water levels in the Detroit River established by Urban Engineering are also included. Note that **Table 1** includes a column labeled "Discrepancy", which shows the difference between the depth of well as recorded in the field borehole logs and that measured during monitoring. Where this discrepancy was greater than 1.0 feet, the well construction portion of the computer-generated borehole log in **Appendix B** was adjusted to agree with the site monitoring data.

Existing monitoring wells suspected of anomalous water levels were also surveyed. The results are contained in **Table 2. Survey Data for Existing Monitoring Wells** in **Appendix C**, which also shows the elevation difference between the current and previous surveys. Changes in the elevation of the monitoring point (top of well) have a direct effect on the resulting water level measurements. The distribution of adjustments to water level data (ΔWL in **Table 2**) is plotted in **Figure 9** below. The distribution of residuals is typical of that for random measurement error. The calculated changes were not considered sufficiently large to warrant adjusting water levels from previous monitoring events. Changes in well elevation due to wells being cut down to flush-mount (well name shaded grey in **Table 2**) are considered a separate case. Monitoring well DNR-2 is another separate case: the well has been damaged and the top of well elevation from the current survey refers to a different (lower) point than previous surveys.

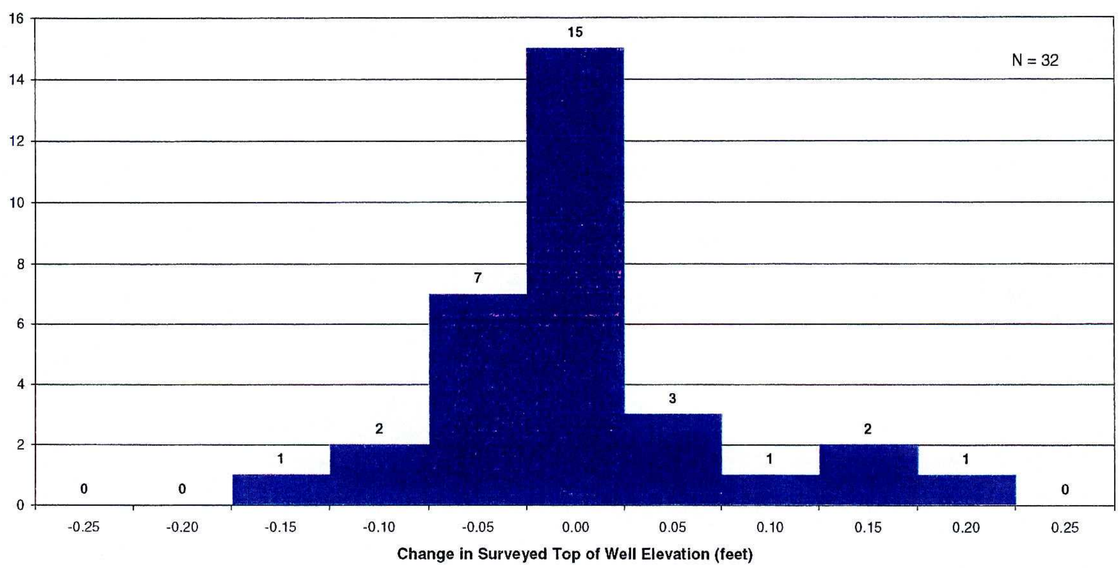


Figure 9. Distribution of Changes to Piezometer Elevation Data

Table 3. Water Level Data and Comparative Statistics in **Appendix C** presents all water level data collected at new and existing monitoring locations. These data are plotted in **Figure 10. Water Level**

Data. Also plotted on this figure are interpolated water level contours, and circles indicating the difference between the February 2002 water level and the average water level recorded in the four previous monitoring events (June 1998, October 1998, December 1999, and April 2001). This average water level has been used to develop calibration targets for the development of the site groundwater flow model (WHI, concurrent). Note that the water level contours on **Figure 10** are illustrative only, as they ignore some hydraulic features within the site, in particular the groundwater extraction system. Cross-section X-X' indicated on **Figure 10** is designed to evaluate the hydraulic influence of the historic shipyard channel at the site. This section is shown on **Figure 11. Cross-Section X-X'**.

As shown on **Figure 11**, the anticipated depression in the water level caused by a hydraulic influence from the historic shipyard channel is not evident. Nonetheless, the water levels in wells CMS-MW-9 and RFIMW-10 do show an apparent "dip", so it may be that the hydraulic influence of the former shipyard channel exists, but does not extend back as far west as WHI-9-4F. The data for the Native Sand unit are not continuous. The data from this limited number of sampling points, and at only one point in time is limited, and no firm conclusion can be made, but the preliminary conclusion is that the shipyard channel plays only a limited role in the flow regime at the site.

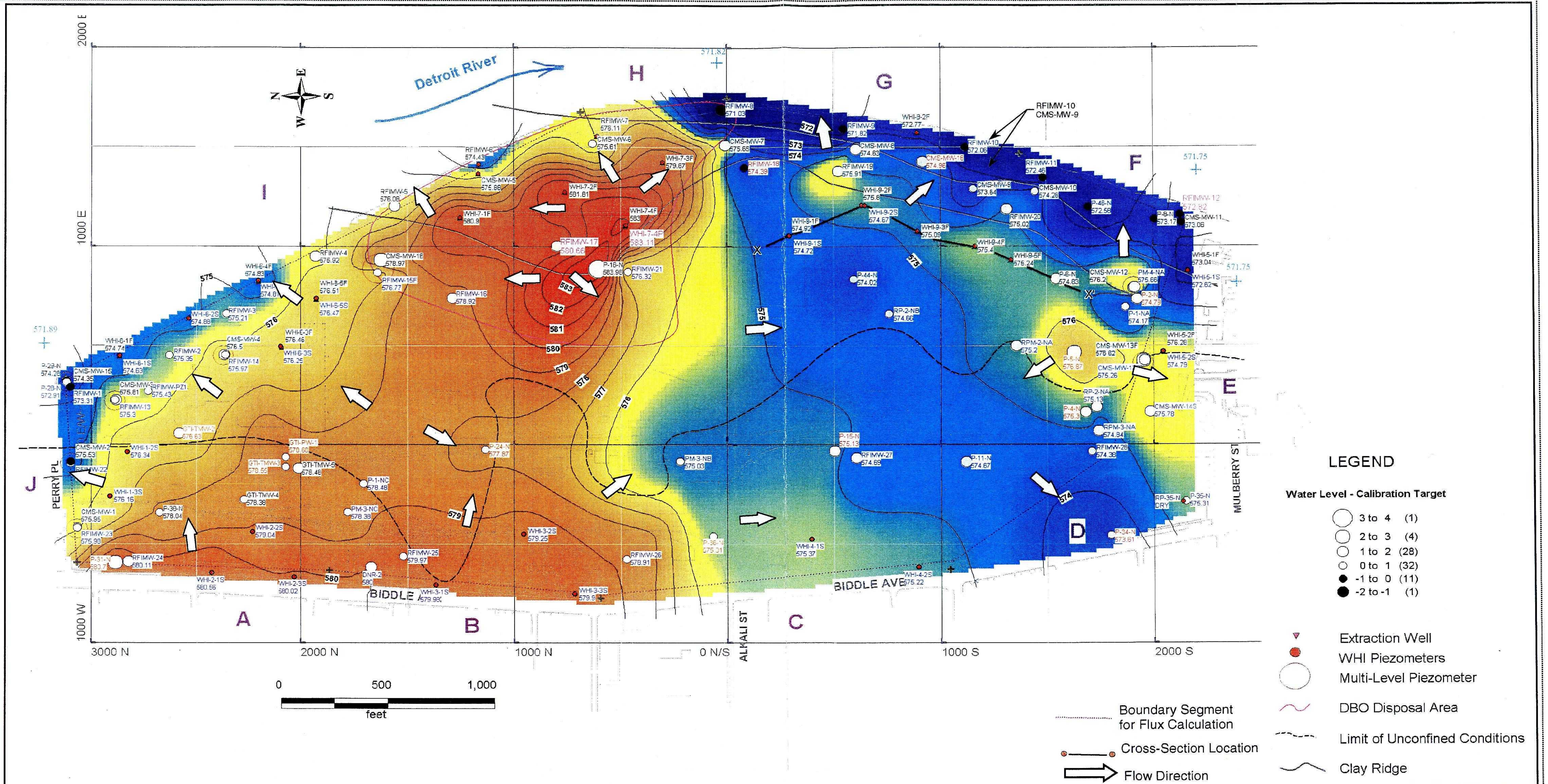
There are 17 piezometer nests at the site, which allow an evaluation of the vertical components of flow. **Table 4. Vertical Flow** in **Appendix C** presents the data and calculations of vertical hydraulic gradient. Vertical flow is downward in almost all parts of the site where piezometer nests exist. On average the water level in the Fill is 0.64 feet higher than that in the underlying Native Sand, and this causes an average downward hydraulic gradient of 5.8%. Note that the P-28-N / P-29-N nest was not used since P-28-N is damaged.

Flow direction is calculated using Darcy's Law in 3 dimensions as:

$$\mathbf{q} = -\mathbf{K} \cdot \nabla h$$

where $\mathbf{q}$ = Darcy flux with components (q_X, q_Y, q_Z) (ft/d)
$\mathbf{K}$ = hydraulic conductivity tensor with principal elements (K_X, K_Y, K_Z) (ft/d)
∇h = gradient of hydraulic head field, with components (i_X, i_Y, i_Z) (ft/ft)

The average vertical gradient (i_Z) in the vicinity of the steel sea-wall is approximately 0.019 ft/ft downward. This can be compared to an average horizontal gradient (i_X) toward the river of 0.007 ft/ft in the Native Sand and 0.013 ft/ft in the Fill (February 2002 data). Though the vertical gradient is slightly higher than the horizontal gradient, the vertical hydraulic conductivity (K_Z) is likely at least an order of magnitude lower. The presence of a confining Peat & Clay layer is intermittent in this part of the site, but any deposit of reduced hydraulic conductivity would severely limit vertical flux. The preliminary conclusion is that flow has some downward vertical component in the vicinity of the steel sea-wall, but horizontal flow likely dominates.



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BASF

Water Level Data

BASF-Wyandotte North Works

Figure 10

Field Investigation

June 2002

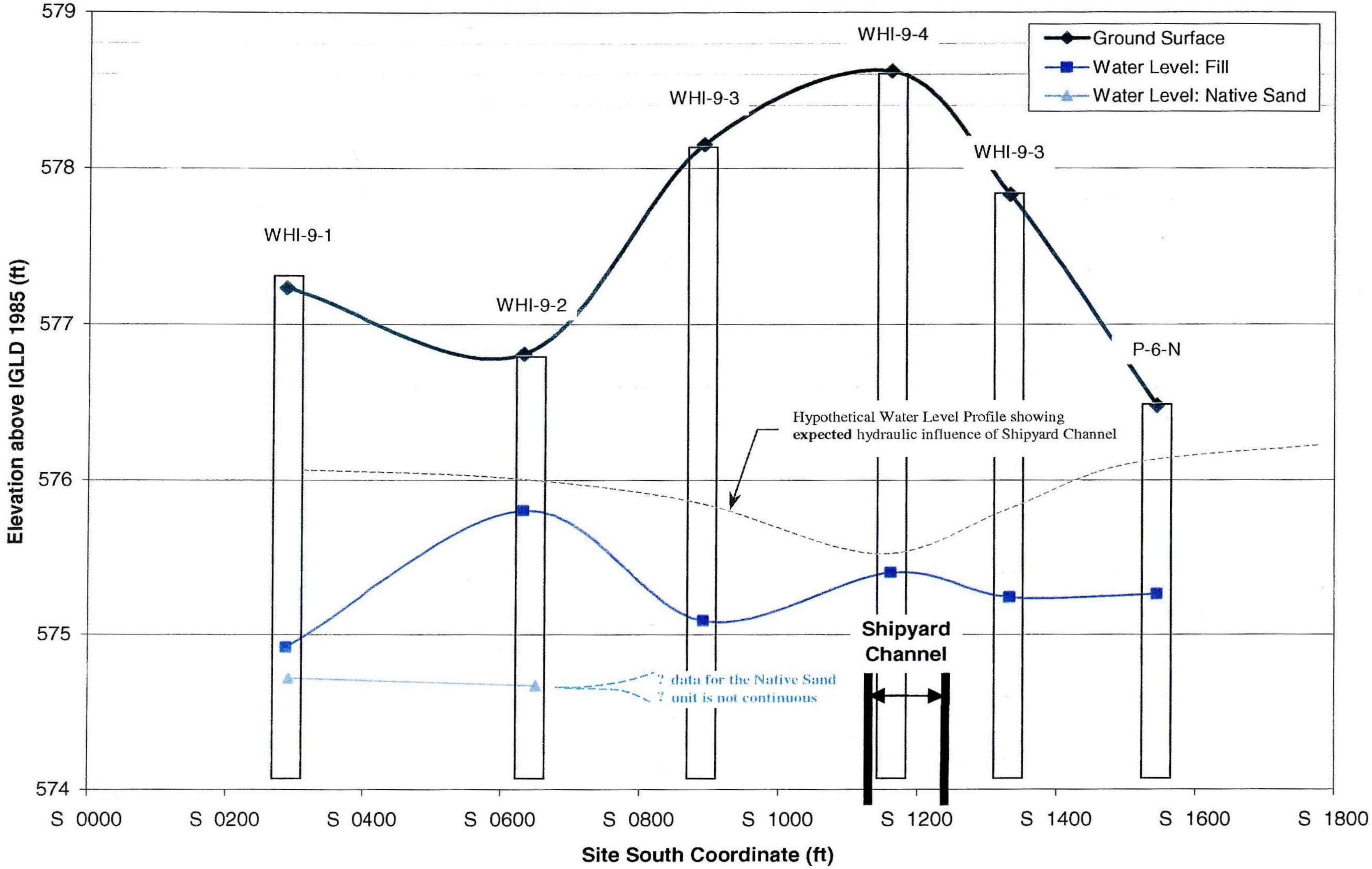


Figure 11. Cross-Section X-X'

As **Table 3** indicates, the average water level measured in February 2002 was 0.89 ft higher than the calibration target. These high water levels are consistent with the results in Papadopulos (1984, Appendix B), in which the highest water levels found in monthly monitoring occurred between December and April.

The resulting river water levels from the extrapolation of NOAA data are shown in **Figure 12** below.

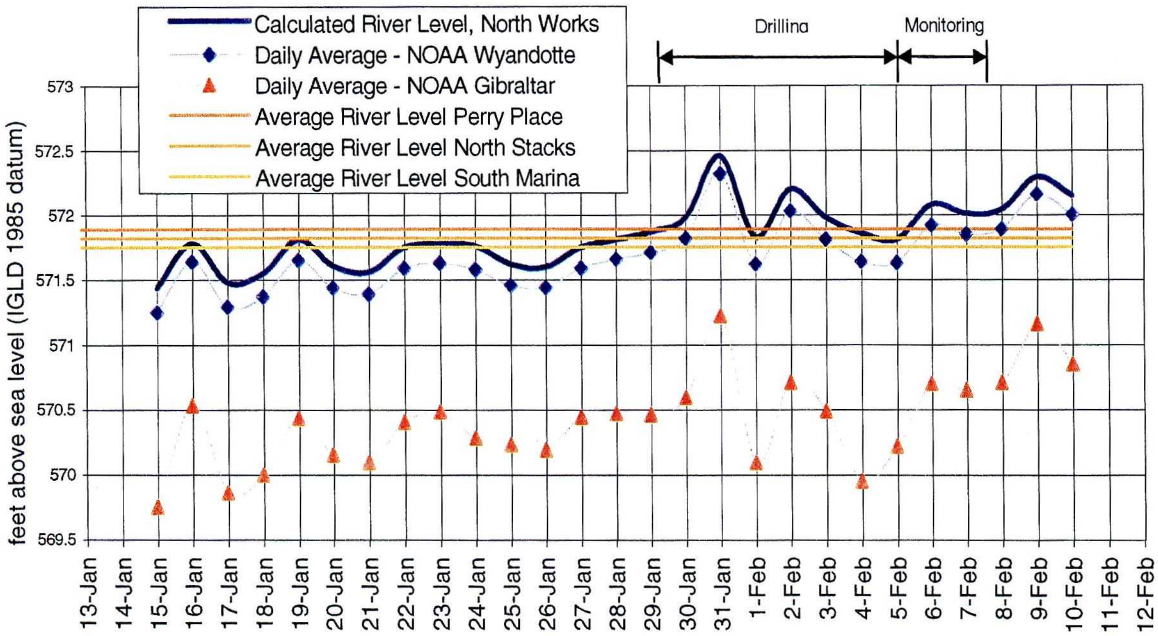


Figure 12. Calculated Water Level in Detroit River

These river levels show significant variation from day to day, demonstrating an upward trend during the period of work. Groundwater levels also vary over time, in response to variations in rainfall for example, but their reaction time is much slower. This is why an averaging period is appropriate when comparing groundwater levels to river levels.

Figure 13. Seasonal Fluctuations attempts to illustrate these annual cycles, by plotting the average of water levels in ***all*** monitoring wells for five monitoring events over the last four years. In additional to the seasonal changes, there may be long-term trends in water levels that **Figure 13** does not consider. Though the analysis is admittedly crude, it supports the idea that groundwater gradients were higher during the February 2002 round of monitoring than is usually the case. As such, groundwater flux estimates developed based on these values should correspondingly over-estimate average conditions.

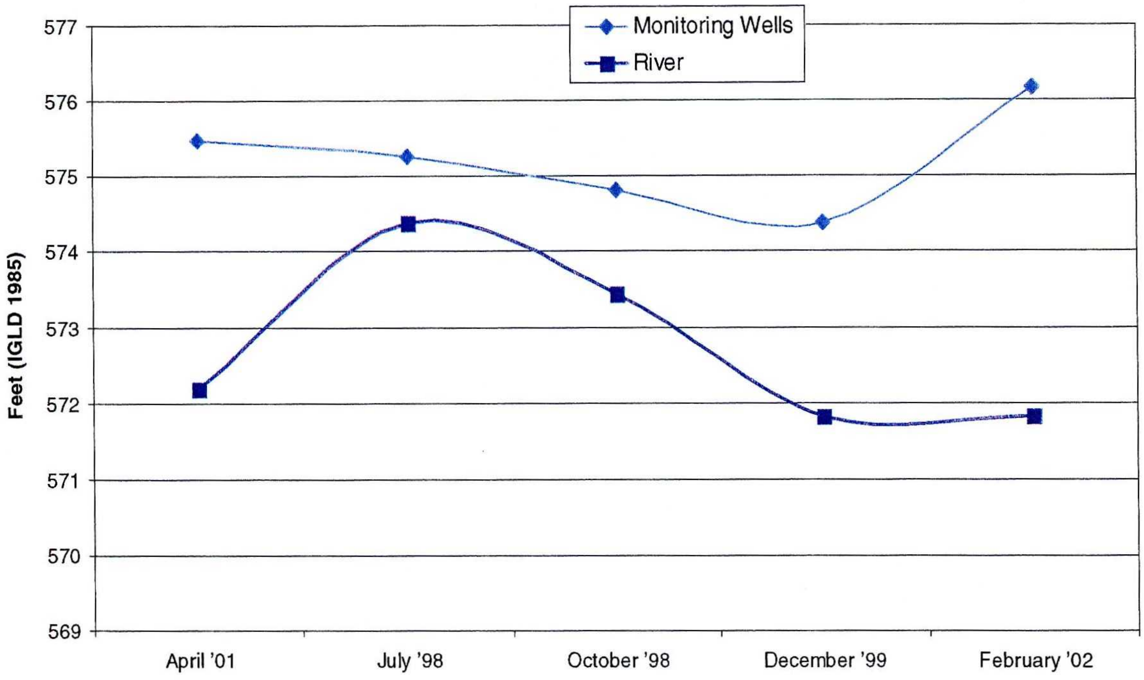


Figure 13. Seasonal Fluctuations

The groundwater flow patterns observed in **Figure 10** are similar to those found in previous monitoring events at the site. Overall, water levels at the site were high – on average 0.89 ft higher – than the calibration target for the numerical groundwater flow model. The areal distribution is not uniform, however, as a careful examination of **Figure 10** shows. Water levels immediately adjacent to the river in the southern portion of the site tend to be ***lower*** than previous (indicated with black circles), whereas levels in the interior portion of the site are almost all ***higher*** (indicated with light grey circles). Thus, hydraulic gradients (and so groundwater flux) based on these data will be higher those using previous monitoring data. This pattern is likely due to low water levels in the Detroit River and the relatively strong hydraulic connection between the river and the groundwater in the southern portion of the site. Interestingly, this pattern is not found along the river in the northern portion of the site, indicating a weaker hydraulic connection with the river, as anticipated due to the presence of a more competent sea-wall in the northern portion of the site.

4.0 CONCLUSIONS

In terms of the five areas of uncertainty to be resolved through additional field investigations, the following conclusions can be drawn:

1. Groundwater flow direction in Fill and Native Sand along boundaries

Groundwater appears to enter the site along the portion of Biddle Avenue north of Alkali, and appears to leave the site along all other boundaries. The flow direction appears to the same in the Fill and Native Sand units for all areas of the site.

2. Groundwater flow direction in Fill and Native Sand along seawall in northern part of site

The flow direction in both units is toward the river. Horizontal flow likely dominates, though there is a component of flow that is downward.

3. Hydraulic influence of former shipyard channel in south eastern part of site

The former shipyard channel may exert a hydraulic influence close to the river, but it is not evident in the field data collected during this investigation approximately 500 ft west of the river. Additional monitoring would help strengthen this preliminary finding.

4. Water levels and stratigraphy along western boundary (Biddle)

The stratigraphy along Biddle Avenue is quite consistent, with the top of Lacustrine Clay found at depths from 5 to 8 feet. The Native Sand was present in all boreholes along Biddle, and is noticeably less silty than in other parts of the site. Water levels are high (580 ft) in the portion of Biddle north of Alkali St., and there is a steep gradient to a lower water level (575 ft) to the south of Alkali.

5. Apparently anomalous water levels in certain wells.

With the exception of several monitoring wells that were cut down, and one well (GTI-TMW-4) which had been incorrectly recorded as a flush-mount, only small, apparently random changes in surveyed elevation were noted. In particular, wells RFIMW-8 and RFIMW-9 continue to show very low water levels.

WHI believes that this Field Investigation has significantly contributed to the understanding of groundwater flow at the North Works site. The data collected and reported herein will aid the development of the numerical groundwater flow model, and make it more representative of actual field conditions. One of the most important contributions of this work is the development of groundwater flux estimates and calibration targets, as described in the model calibration report.

We wish to thank BASF for allowing WHI to continue our participation in this interesting and challenging project, and look forward to completing the development of the numerical flow model.

Yours very truly,
WATERLOO HYDROGEOLOGIC, INC.

David Tamblyn, M.Eng., P.Eng.
Environmental Engineer

Paul J. Martin, M.Sc., P.Eng.
Manager, Consulting Services

D:\projects\BASF-Wyandotte\docs\NW Field Investigation Report Draft Final.doc

APPENDIX A – GEOPROBE DETAILS

Geoprobe's Dual Tube Sampling Systems are efficient methods of collecting continuous soil cores with the added benefit of a cased hole. Dual tube sampling uses two sets of probe rods to collect continuous soil cores. One set of rods is driven into the ground as an outer casing. These rods receive the driving force from the hammer and provide a sealed hole from which soil samples may be recovered without the threat of cross contamination. The second, smaller set of rods are placed inside the outer casing. The smaller rods hold a sample liner in place as the outer casing is driven one sampling interval. The small rods are then retracted to retrieve the filled liner.
(ref. http://www.geoprobe.com/products/tools/sampling_tools/soil/dual_tube_menu.htm)

Dual Tube Sampling benefits include:

- Continuous coring for faster sampling in depths over 20 feet
- Cased hole eliminates cross contamination
- Optional solid drive tip seals system for driving to top of sampling interval or for split interval sampling
- Option to perform bottom-up pressure grouting while retracting outer casing
- Set monitoring wells through outer casing after collection of soil cores.

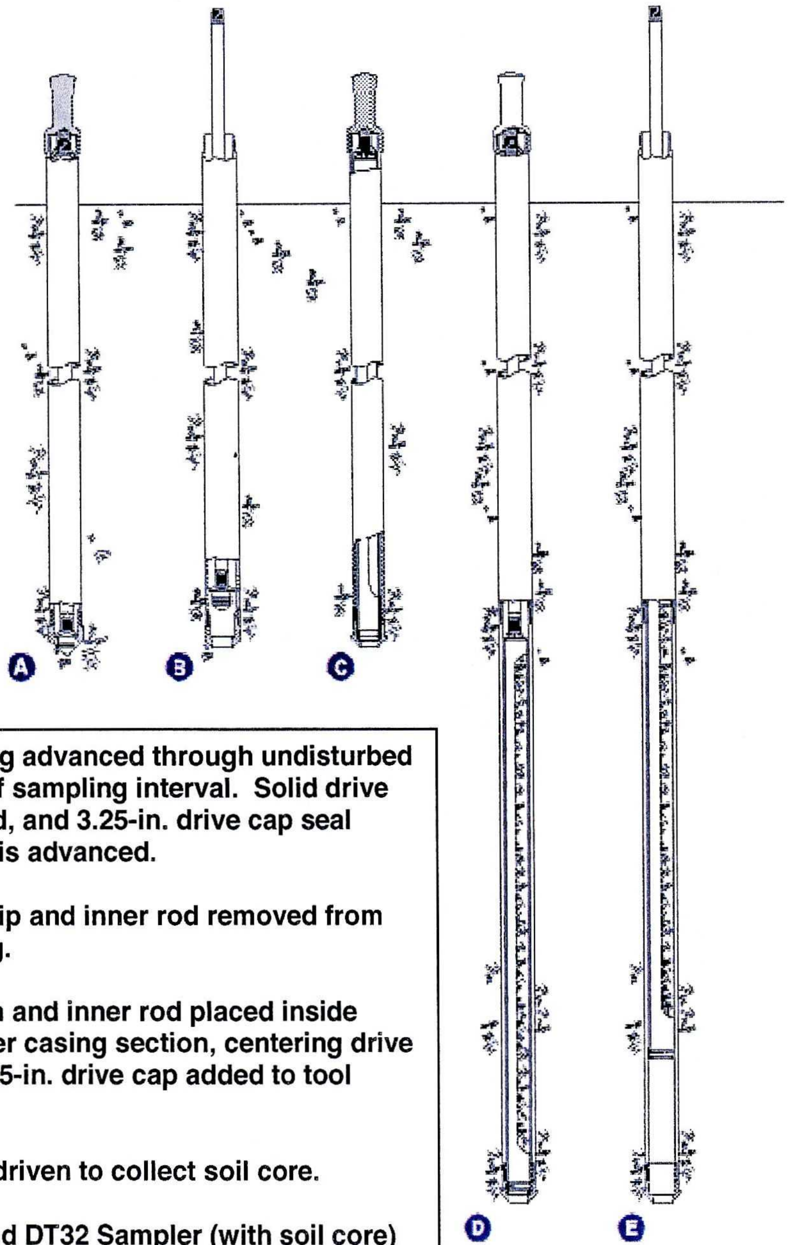
(ref. http://www.geoprobe.com/products/tools/sampling_tools/soil/dual_tube_menu.htm)

The Geoprobe 66DT track-mounted percussion probing machine features:

- 32 Hz percussion rate
- Down Force 35,000 lbs. (160 kN)
- Retraction Force 47,000 lbs. (214 kN)

DT32 sampling system features:

- designed for use with 3.25-inch probe rods
- Retrieves 2.0-inch soil cores
- Core catcher for sampling loose soils
- Window sheath to alleviate problems with failed liners
- Solid drive point for driving to discrete depths before sampling
- Expendable cutting shoe for setting monitoring wells
- 5-foot sampling capacity
- Integrated with the use of 1.25-in. probe rods
- Durability needed to withstand Geoprobe's GH60 hammer



A. **Cutter casing advanced through undisturbed soil to top of sampling interval. Solid drive tip, inner rod, and 3.25-in. drive cap seal casing as it is advanced.**

B. **Solid drive tip and inner rod removed from outer casing.**

C. **DT32 stealth and inner rod placed inside casing. Outer casing section, centering drive cap, and 3.25-in. drive cap added to tool string.**

D. **Tool string driven to collect soil core.**

E. **Inner rod and DT32 Sampler (with soil core) retrieved.**

(ref. http://www.geoprobe.com/products/tools/sampling_tools/soil/dt32dwg.htm)

Geoprobe DT32 Sampling System

Deflection of Geoprobe Off-Vertical (WHI-9-2F)

APPENDIX B – BORHOLE LOGS

Notes:

1. The following logs contain details of the lithology and well construction for all boreholes drilled during the present Field Investigation at the BASF Wyandotte North Works site.
2. The boreholes are grouped into 9 Zones around the site, and are numbered WHI-Z-NU, where Z is the Zone (1 to 9), N is the borehole number within that Zone, and U is the hydrostratigraphic unit where the well screen is located (F for Fill, S for Native Sand, P for Peat, X for boreholes with no well).
3. All elevations are measured in feet relative to IGLD 1985.
4. The first log is a **Legend** explaining the symbols used in the subsequent logs.

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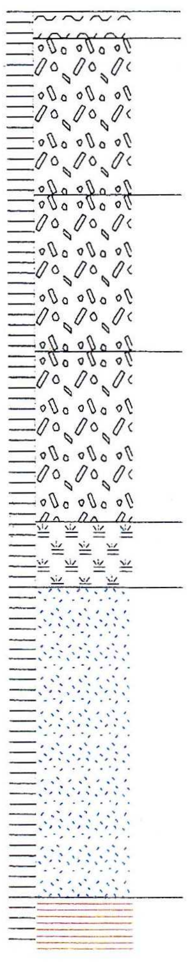
BOREHOLE N° : WHI-1-2S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 05 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 581.68	GROUT TYPE	: Bentonite
TOP OF CASING	: 581.56	DEPTH TO WATER	: 5.22 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 576.34
REMARKS	: N 2832 W 0037		



TOPSOIL, sandy, brown

FILL - COARSE GRAINED, sand & gravel, coarse, grey, damp

FILL - COARSE GRAINED, granular, lime waste, grey white, moist. wet @ 5'

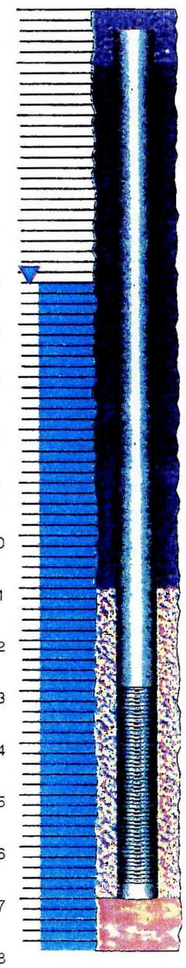
FILL - COARSE GRAINED, cinders, black, coarse, gravelly, wet

PEAT, dark grey, sandy, spongey, moist - wet

FINE SAND, dark grey-brown, some silt, organics to 13', wet. grading to light brown. No sample 15-17'.

CLAY, stiff. No sample.

END OF BOREHOLE @ 18'



COMMENT: IGLD 1985 DATUM

Piezometer nest not installed: water level in deep piezometer same as logged in the fill- i.e. 5 '

Probe stuck at 18' - unable to retrieve sample

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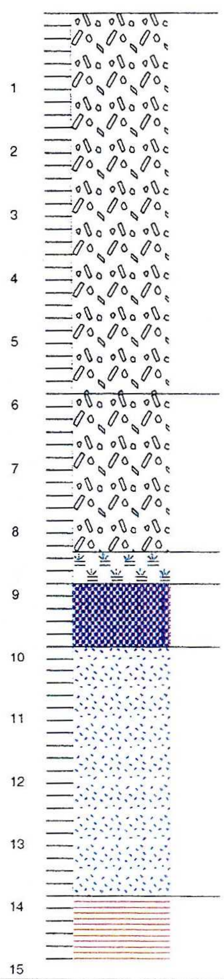
BOREHOLE N° : WHI-1-3S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 05 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 580.01	GROUT TYPE	: Bentonite
TOP OF CASING	: 579.77	DEPTH TO WATER	: 3.61 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 576.16
CO-ORDINATES	: N 2911 W 0260		



FILL - COARSE GRAINED, granular, trace lime, moist. wet @ 5'

FILL - COARSE GRAINED, lime, light grey - bluish, granular, moist

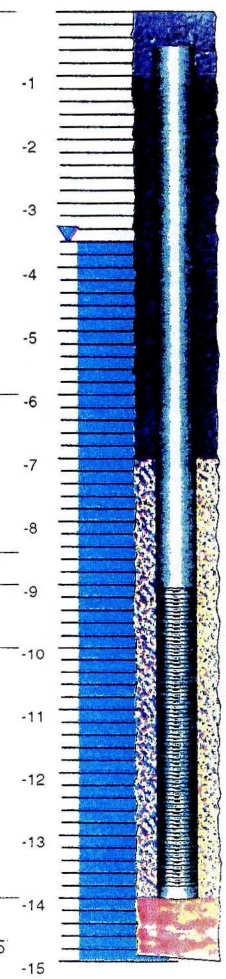
PEAT, black, sandy, silty, soft, moist

ORGANIC SAND AND SILT, black, soft, wet

FINE SAND, grey, silty to some silt, loose, wet

CLAY, grey, silty, some sand, trace gravel, firm grading to soft, wet.

END OF BOREHOLE @ 15'



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Screen
Concrete
Native soil
Annular Seal
Water Level

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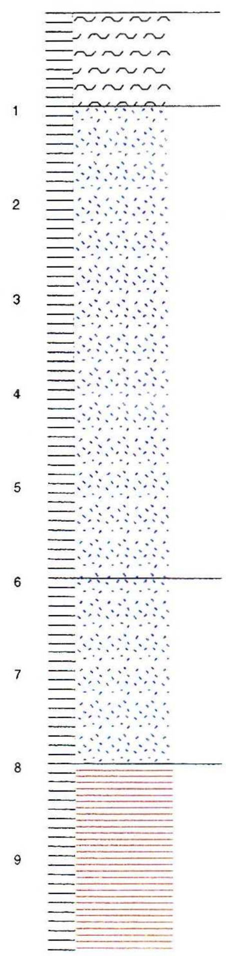
BOREHOLE N° : WHI-2-1S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 07 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 584.72	GROUT TYPE	: Bentonite
TOP OF CASING	: 584.49	DEPTH TO WATER	: 3.93 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 580.56
CO-ORDINATES	: N 2430 W 0647		



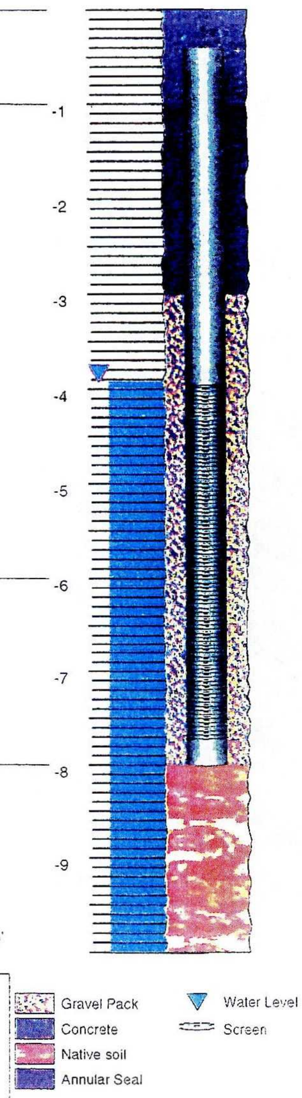
TOPSOIL, brown, sandy loam, moist, good grass cover

FINE SAND, brown, trace to some silt, moist. grading to golden, then to reddish golden. wet @ 3.5'

FINE SAND, grey, very fine grading to fine, some silt. wet. some dilatency. typical example of Native Sand

CLAY, grey, some silt, occasional gravel, stiff, wet.

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM

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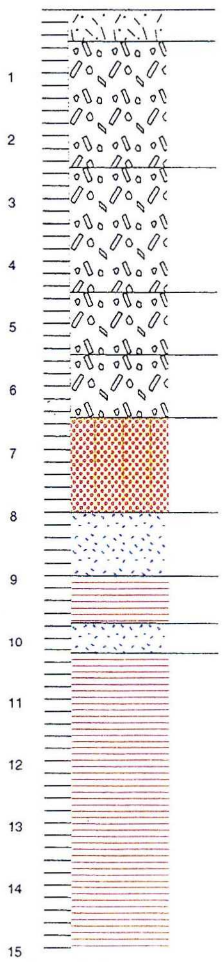
BOREHOLE N° : WHI-2-2S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 05 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 581.93	GROUT TYPE	: Bentonite
TOP OF CASING	: 581.71	DEPTH TO WATER	: 2.67 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 579.04
CO-ORDINATES	: N 2233 W 0440		



FILL - MEDIUM GRAINED, silty, sandy, trace gravel

FILL - COARSE GRAINED, lime, cinders, sand & gravel, thin layers, moist. wet @ 3'

FILL - COARSE GRAINED, lime, light grey/white, wet

FILL - COARSE GRAINED, cinders, dark grey, wet

FILL - COARSE GRAINED, sand & gravel, grey, brown, wet

ORGANIC SILT, dark grey, sandy, wet - moist. 2" clay, grey, black mottling, soft, wet @6.5'

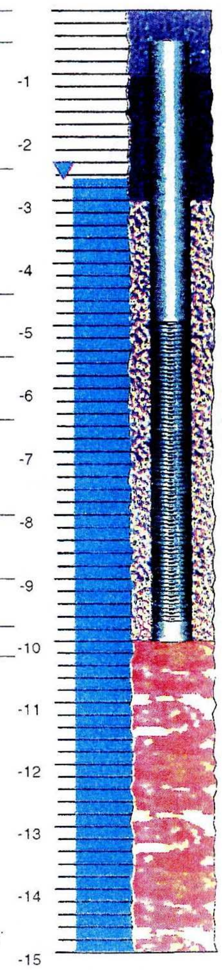
FINE SAND, grey - brown, silty, wet

CLAY, blue, grey, black, mottling, trace gravel, firm, wet

FINE SAND, brown, some silt, wet

CLAY, brown, blue mottling to 11', some gravel, very firm , wet. grading to hard, then firm

END OF BOREHOLE @ 15'



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

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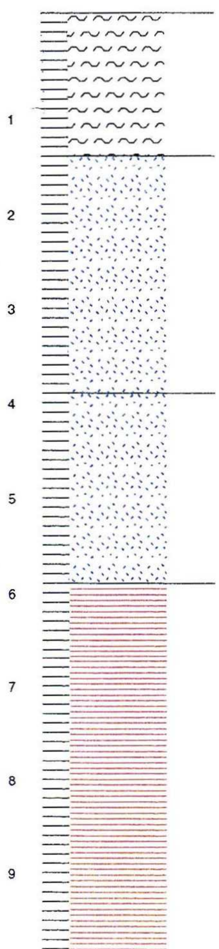
BOREHOLE N° : WHI-2-3S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 07 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 583.50	GROUT TYPE	: Bentonite
TOP OF CASING	: 583.20	DEPTH TO WATER	: 3.18 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 580.02
CO-ORDINATES	: N 2032 W 0668		



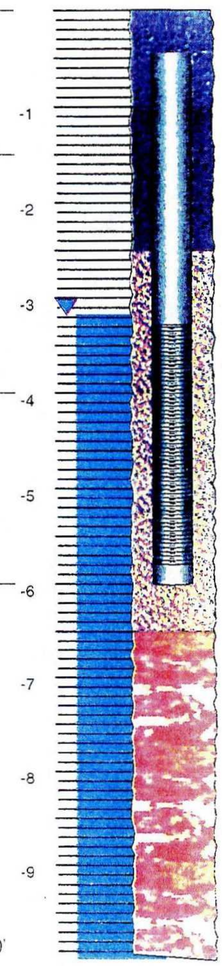
TOPSOIL, dark grey - brown, sandy, loamy, soft, moist. good grass cover.

FINE SAND, brown, some silt, moist, grading toreddish-golden, very fine wet @ 3.5'

FINE SAND, grey, trace silt, wet

CLAY, grey, silty, occasional gravel, stiff, wet, grading to some silt, soft

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

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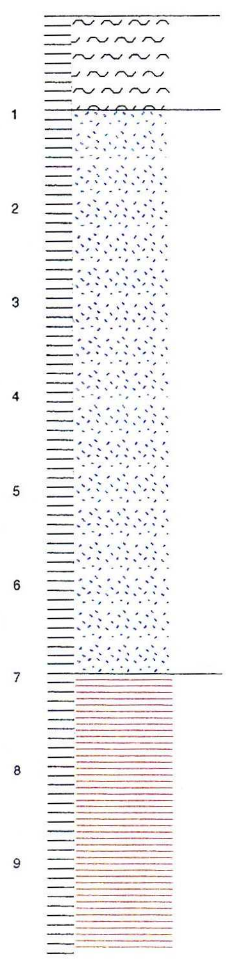
BOREHOLE N° : WHI-3-1S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 06 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 583.68	GROUT TYPE	: Bentonite
TOP OF CASING	: 583.50	DEPTH TO WATER	: 3.52 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 579.98
CO-ORDINATES	: N 1366 W 0709		

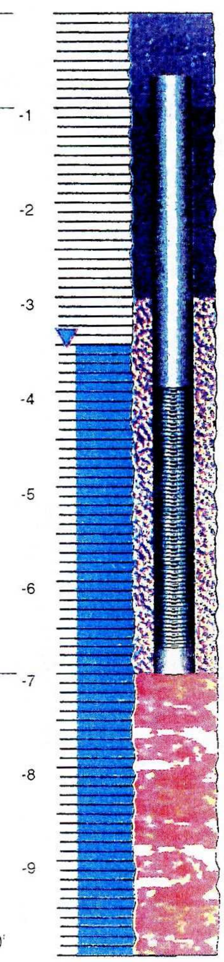


TOPSOIL, brown

FINE SAND, brown, some silt, moist, grading to medium, golden, trace silt. wet @ 4'

CLAY, grey, silty, trace gravel, stiff, wet. grading to some silt

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

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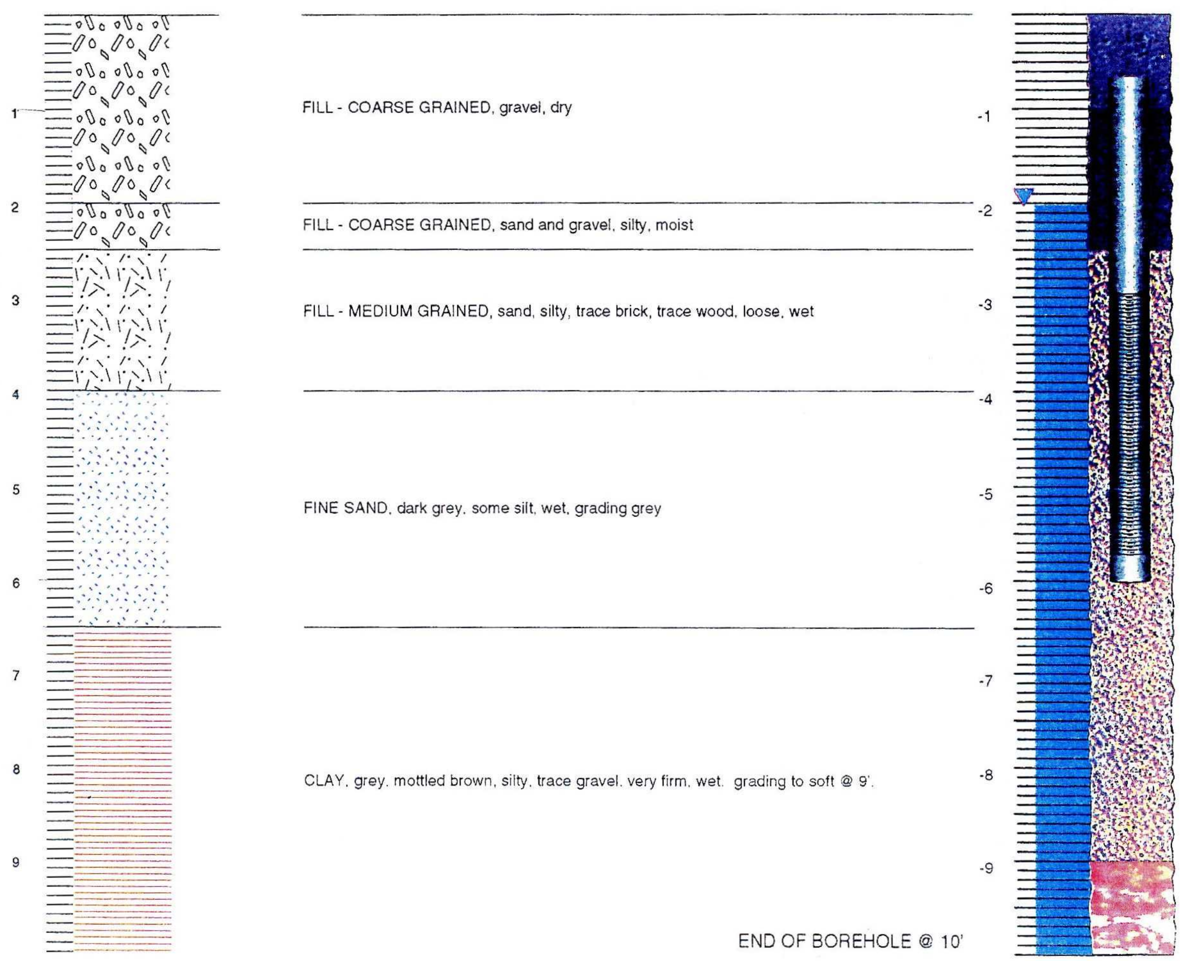
BOREHOLE N° : WHI-3-2S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 05 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 581.49	GROUT TYPE	: Bentonite
TOP OF CASING	: 581.28	DEPTH TO WATER	: 2.03 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 579.25
CO-ORDINATES	: N 0954 W 0452		



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

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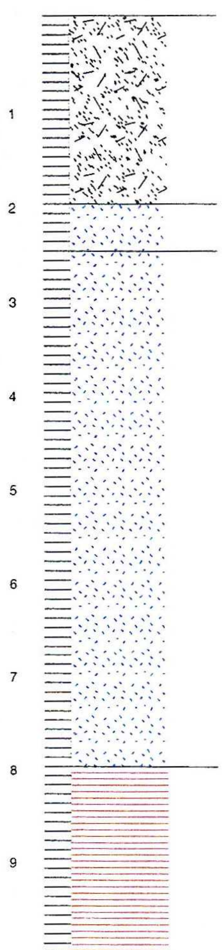
BOREHOLE N° : WHI-3-3S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 06 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 585.20	GROUT TYPE	: Bentonite
TOP OF CASING	: 584.95	DEPTH TO WATER	: 5.05 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 579.90
CO-ORDINATES	: N 0717 W 0753		



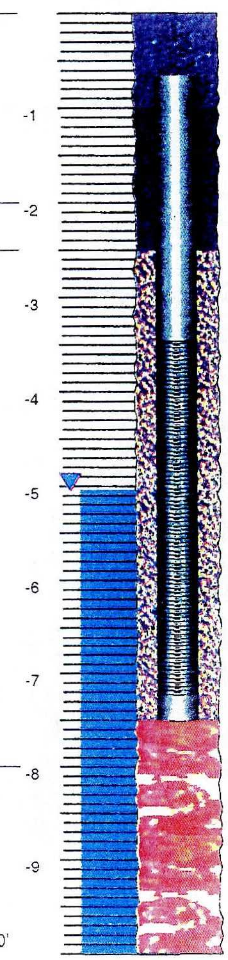
FILL - FINE GRAINED, silt, dark grey, sand lenses, moist. good grass cover.

FINE SAND, grey, some silt, trace rootlets, moist

FINE SAND, golden, trace silt, moist, grading to medium grained. wet @7.5'

CLAY, grey, silty, occasional gravel, wet.

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

waterloo hydrogeologic
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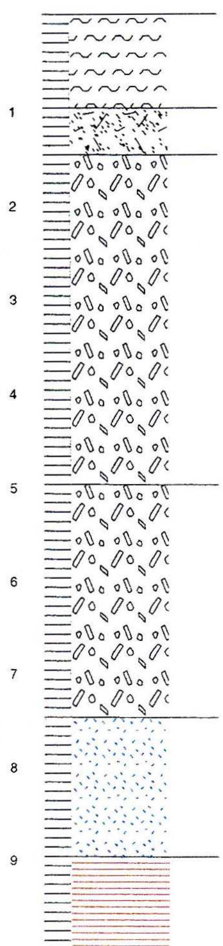
BOREHOLE N° : WHI-4-1S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 06 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 578.14	GROUT TYPE	: Bentonite
TOP OF CASING	: 577.98	DEPTH TO WATER	: 2.61 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 575.37
CO-ORDINATES	: S 0396 W 0477		



TOPSOIL, sandy, wet. frozen 3"-5"

FILL - FINE GRAINED, clay, brown, firm, moist-wet

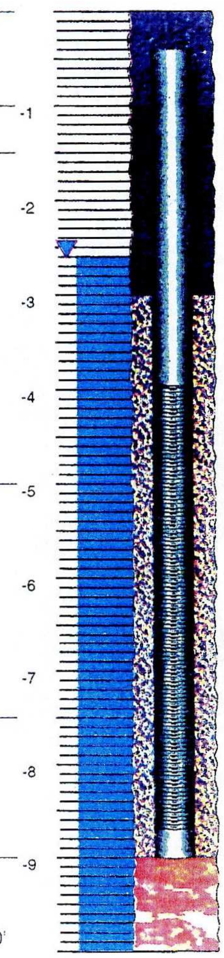
FILL - COARSE GRAINED, sand and gravel, dark grey, silty, wet. grading to brown

FILL - COARSE GRAINED, cinders, granular, dark grey, wet

FINE SAND, grey, trace silt, wet. grading to dark grey, very silty, trace organics 8.5'-9'

CLAY, grey, mottled brown, some silt, trace gravel, firm, wet.

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

waterloo hydrogeologic
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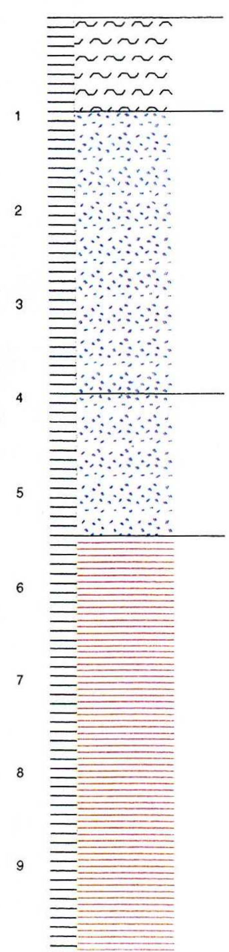
BOREHOLE N° : WHI-4-2S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 06 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 577.95	GROUT TYPE	: Bentonite
TOP OF CASING	: 577.67	DEPTH TO WATER	: 2.45 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 575.22
CO-ORDINATES	: S 0894 W 0619		



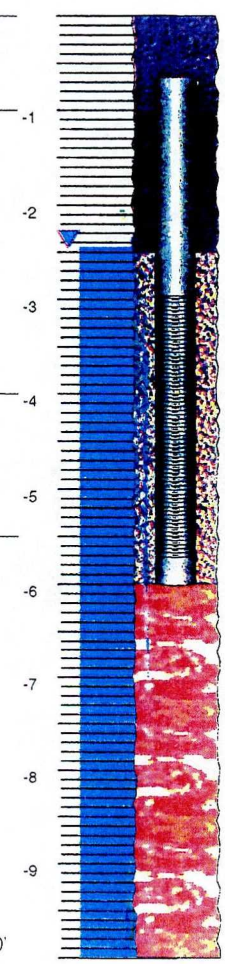
TOPSOIL, brown, sandy, some silt, moist

FINE SAND, brown, some silt, moist. wet @ 2.5'

FINE SAND, golden, wet

CLAY, grey, some silt, occasional gravel, firm, grading softer

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM
varves present in CLAY but very disturbed

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

waterloo hydrogeologic

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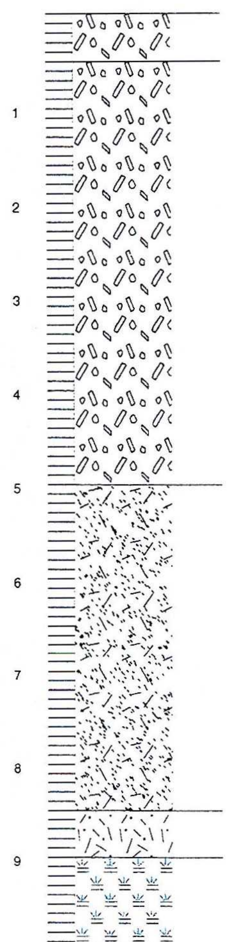
BOREHOLE N° : WHI-5-1F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 01 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 576.16	GROUT TYPE	: Bentonite
TOP OF CASING	: 575.74	DEPTH TO WATER	: 2.70 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 573.04
CO-ORDINATES	: S 2162 E 0877		



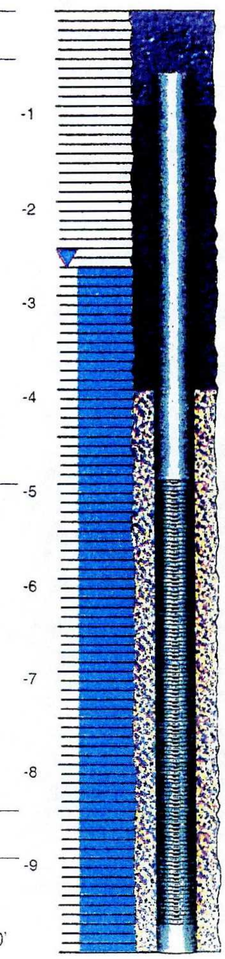
FILL - COARSE GRAINED, granular, some rootlets

FILL - COARSE GRAINED, black, granular, slag, angular, occasional sand seams, wet

FILL - FINE GRAINED, dark grey, slurry, fine grained, very loose - liquified, wet

FILL - MEDIUM GRAINED, sand, gery, wood fragements, wet

PEAT, brown, mossy, spongey, wet



END OF BOREHOLE @ 10'

COMMENTS: IGLD 1985 DATUM
stratigraphy inferred from WHI-5-1S: 3' west

Gravel Pack
Screen
Concrete
Annular Seal
Water Level

waterloo hydrogeologic
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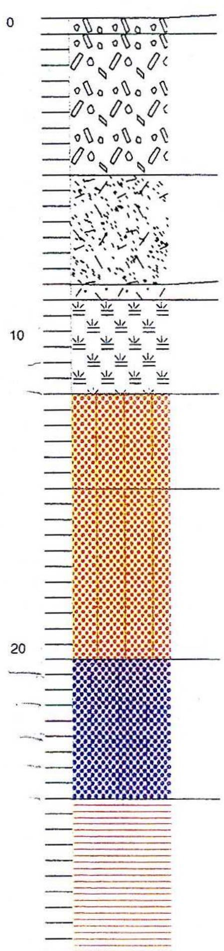
BOREHOLE N° : WHI-5-1S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 01 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 576.15	GROUT TYPE	: Bentonite
TOP OF CASING	: 575.61	DEPTH TO WATER	: 2.99 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 572.62
CO-ORDINATES	: S 2161 E 0874		



FILL - COARSE GRAINED, granular, some rootlets

FILL - COARSE GRAINED, black, granular, slag, angular, occasional sand seams, wet

FILL - FINE GRAINED, dark grey, slurry, fine grained, very loose - liquified, wet

FILL - MEDIUM GRAINED, sand, gery, wood fragements, wet

PEAT, brown, mossy, spongey, wet, grading to silty, brown

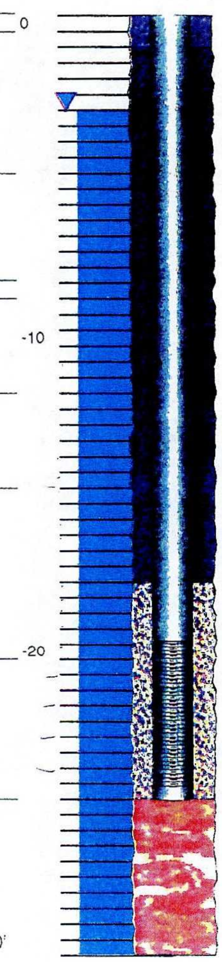
ORGANIC SILT, brown, trace wood, very soft

SILT, gery, clayey, trace sand, trace organics, very soft, wet

SAND AND SILT, grey, some shell fragments, loose. 2" silt seam @ 23.5'

CLAY, grey, some silt, trace gravel, soft, wet

END OF BOREHOLE @ 30'



COMMENTS: IGLD 1985 DATUM
see also WHI-5-1F: 3' east

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

waterloo hydrogeologic
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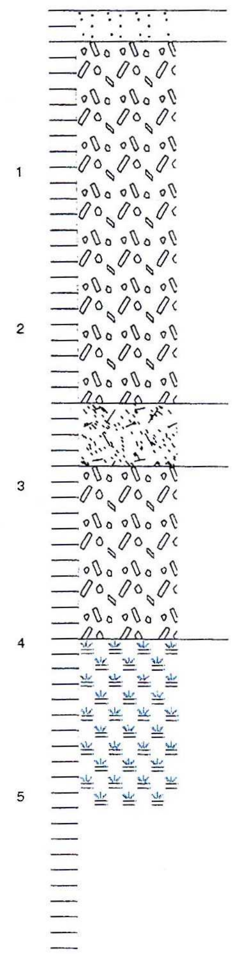
BOREHOLE N° : WHI-5-2F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 06 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 577.47	GROUT TYPE	: Bentonite
TOP OF CASING	: 577.27	DEPTH TO WATER	: 0.99 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 576.28
CO-ORDINATES	: S 2043 E 0470		



ASPHALT

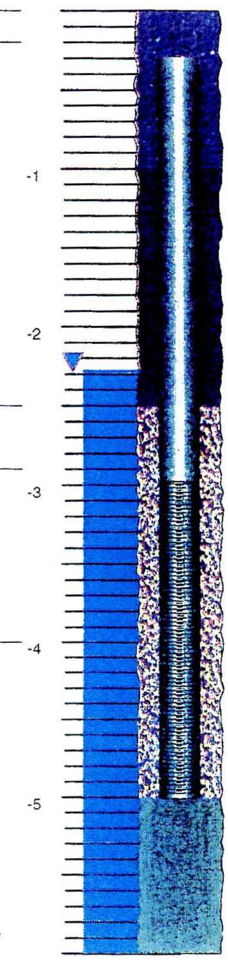
FILL - COARSE GRAINED, sand and gravel, dense, moist. wet @ 2.5'

FILL - FINE GRAINED, clay,grey, silty, trace gravel, wet

FILL - COARSE GRAINED, cinders, black, gravelly, wet

PEAT, dark grey, silty sandy texture, trace rootlets, wet - moist

END OF BOREHOLE @ 5'



COMMENTS: IGLD 1985 DATUM
stratigraphy inferred from WHI-5-2S: 4' south

Gravel Pack
Screen
Concrete
Annular Seal
Water Level

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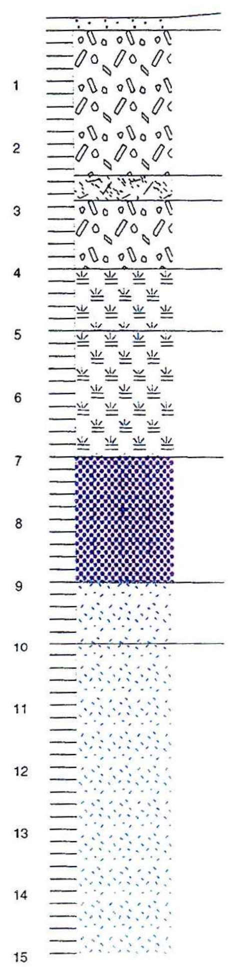
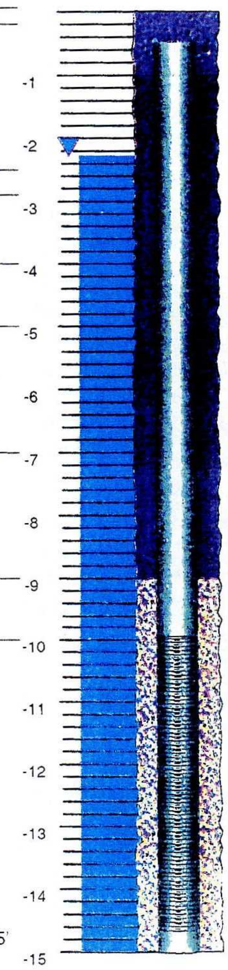
BOREHOLE N° : WHI-5-2S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 06 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 577.40	GROUT TYPE	: Bentonite
TOP OF CASING	: 577.07	DEPTH TO WATER	: 2.28 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 574.79
CO-ORDINATES	: S 2047 E 0471		



Depth	Description
0	ASPHALT
0–2.5	FILL - COARSE GRAINED, sand and gravel, dense, moist. wet @ 2.5'
2.5–2.6	FILL - FINE GRAINED, clay,grey, silty, trace gravel, wet
2.6–3.9	FILL - COARSE GRAINED, cinders, black, gravelly, wet
3.9–4.9	PEAT, dark grey, silty sandy texture, trace rootlets, wet - moist
4.9–6.9	WOOD, red, decomposed fibres and fragments, grading more decomposed
6.9–8.9	ORGANIC SAND AND SILT, dark grey, trace clay, very soft, wet, grading grey, silty, some organic
8.9–9.9	FINE SAND, grey, silty, trace to some organic, wet, grading light grey
9.9–15	FINE SAND, grey, silty, firm, dilatency, grading brown then grey again

END OF BOREHOLE @ 15'



COMMENTS: IGLD 1985 DATUM
see also WHI-5-2F: 4' north

BH was not be extended deeper due to risk of jamming in quicksand

Gravel Pack
Concrete
Annular Seal
Water Level
Screen

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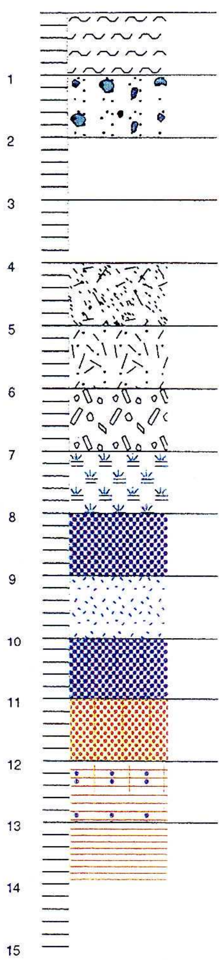
BOREHOLE LEGEND

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 575 to 585 ft amsl	GROUT TYPE	: Bentonite
TOP OF CASING	: typically 2 to 6 inches below grade	DEPTH TO WATER	: < 1' to >10'
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 573 to 583 ft amsl

Lithology Symbols



TOPSOIL - typically 2 - 6 inches

CONCRETE - commonly encountered at depths from 2 - 7 ft

VOID - apparent subsurface cavities

NO RECOVERY - can occur if a stone, etc. blocks the entrance to the Geoprobe sampler

FILL - FINE GRAINED - silts, clays, DBO, etc.

FILL - MEDIUM GRAINED - sands, some lime waste, etc.

FILL - COARSE GRAINED - gravels, cinders, slag

PEAT - brown to black - commonly the first native material encountered

MEDIUM SAND - yellow - found along Biddle Avenue

FINE SAND - grey to grey-brown - very common as a fine to very fine silty sand overlying the Lacustine Clay

SAND AND SILT - found towards the Detroit River

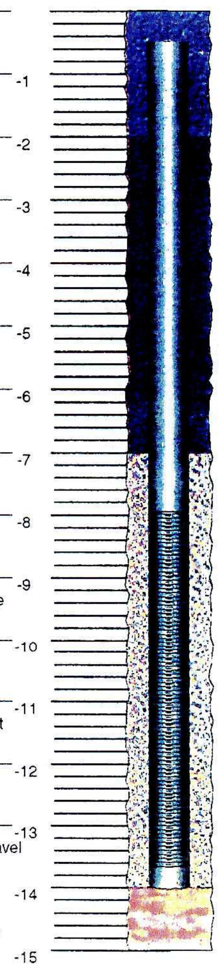
SILT - found as ORGANIC SILT, but may occur without organic - difficult to distinguish without hydrometry

SILT AND CLAY - as above, not identified but may occur

CLAY - blue to grey to brown - common at the site - typically silty with some sand and trace gravel

END OF BOREHOLE @ 15'

Well Completion



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Native soil
Annular Seal
Screen

waterloo hydrogeologic
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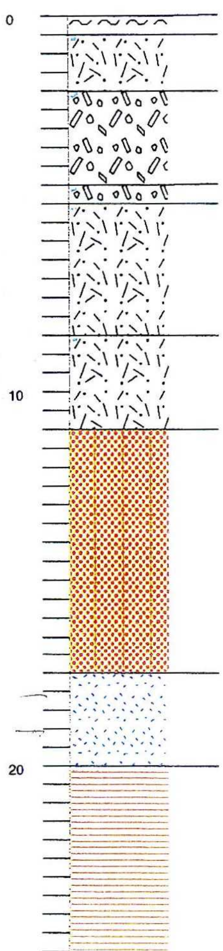
BOREHOLE N° : WHI-6-1S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 04 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 578.28	GROUT TYPE	: Bentonite
TOP OF CASING	: 578.16	DEPTH TO WATER	: 3.53 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 574.63
CO-ORDINATES	: N 2869 E 0449		



TOPSOIL, brown, wet

FILL - MEDIUM GRAINED, sand, brown, some silt, wet

FILL - COARSE GRAINED, coarse sand, brown-grey, very loose, wet

FILL - COARSE GRAINED, medium gravel, wet

FILL - MEDIUM GRAINED, sand, dark grey, silty, very loose, wet

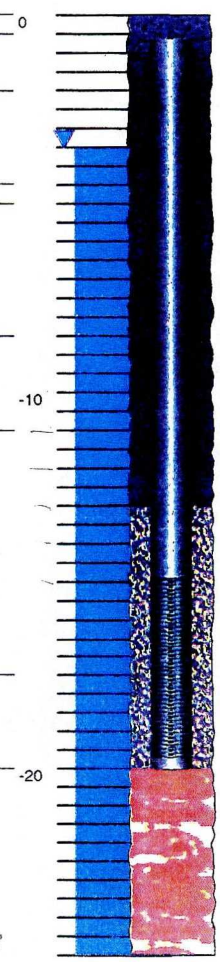
FILL - MEDIUM GRAINED, lime waste, sand-sized grains, some silt-sized grains,dense, wet

ORGANIC SILT, brown, some sand to sandy, trace rootlets, wet

FINE SAND, grey, slity, interbedded with SILT as above, wet. 1" grey clay seam @19.75'

CLAY, grey with dark grey mottling, silty, trace sand, soft, wet.

END OF BOREHOLE @ 25'



COMMENTS: IGLD 1985 DATUM

see also WHI-6-1F: 3' east

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

waterloo hydrogeologic
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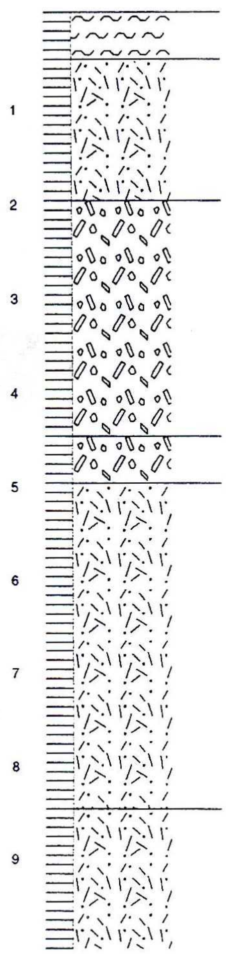
BOREHOLE N° : WHI-6-1F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 04 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 578.31	GROUT TYPE	: Bentonite
TOP OF CASING	: 578.10	DEPTH TO WATER	: 3.36 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 574.74
CO-ORDINATES	: N 2868 E 0446		



TOPSOIL, brown, wet

FILL - MEDIUM GRAINED, sand, brown, some silt, wet

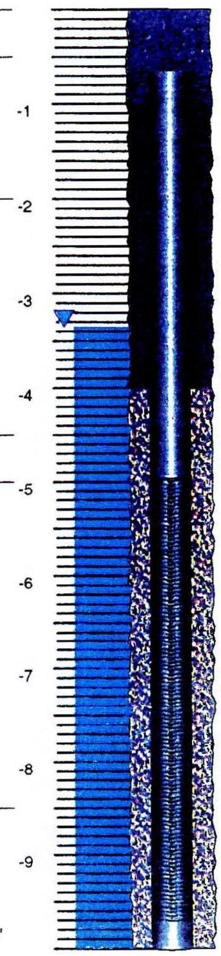
FILL - COARSE GRAINED, coarse sand, brown-grey, very loose, wet

FILL - COARSE GRAINED, medium gravel, wet

FILL - MEDIUM GRAINED, sand, dark grey, silty, very loose, wet

FILL - MEDIUM GRAINED, lime waste, sand-sized grains, some silt-sized grains,dense, wet

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM

stratigraphy inferred from WHI-6-1S: 3' west

Gravel Pack
Concrete
Annular Seal
Water Level
Screen

waterloo hydrogeologic
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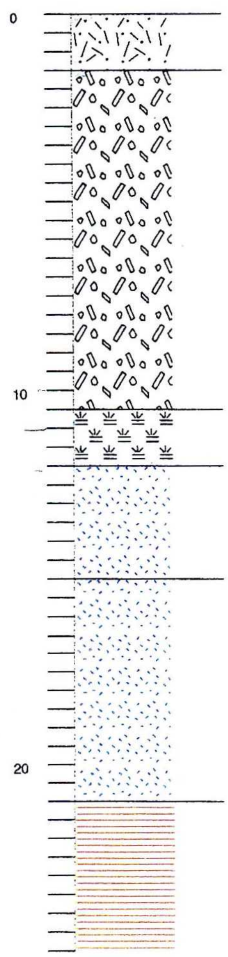
BOREHOLE N° : WHI-6-3S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 01 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 580.77	GROUT TYPE	: Bentonite
TOP OF CASING	: 580.20	DEPTH TO WATER	: 3.95 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 576.25
CO-ORDINATES	: N 2097 E 0494		



FILL - MEDIUM GRAINED, granular, brown, moist, grading to clayey

FILL - COARSE GRAINED, cinders, black, granular, slag-like, moist. wet @ 5'

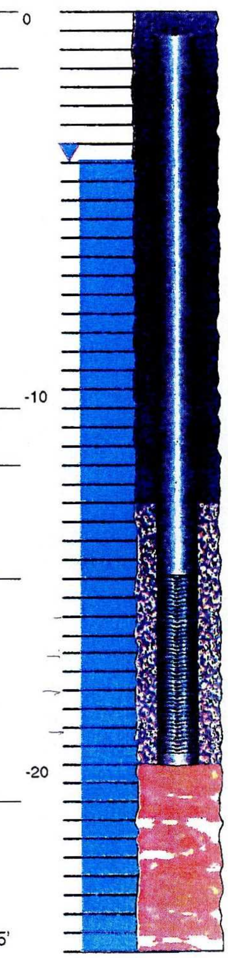
PEAT, black, spongey, grading to ORGANIC SILT, grey, clayey, wet

FINE SAND, grey, silty, trace organics, wet, grading to some silt

FINE SAND, same as above, some organics and brown silt 17'-18'

CLAY, grey, silty, soft, wet, grading to some silt

END OF BOREHOLE @ 25'



COMMENTS: IGLD 1985 DATUM
see also 6-3F: 5' southwest

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

waterloo hydrogeologic
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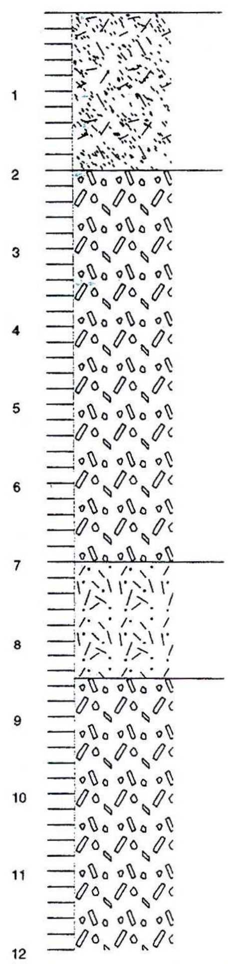
BOREHOLE N° : WHI-6-4F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 04 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 580.84	GROUT TYPE	: Bentonite
TOP OF CASING	: 580.72	DEPTH TO WATER	: 5.89 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 574.83
CO-ORDINATES	: N 2205 E 0823		



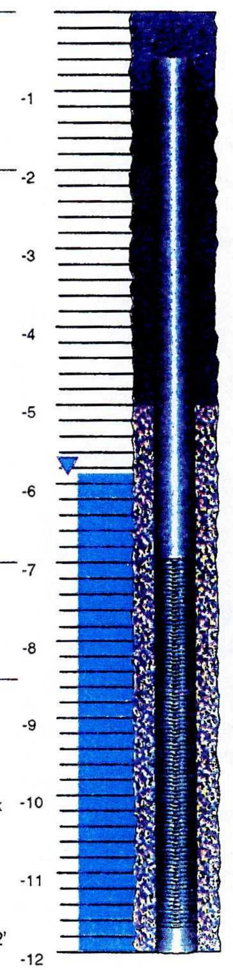
FILL - FINE GRAINED, silt and sand, brown, clayey, moist

FILL - COARSE GRAINED, sand and gravel, grey, damp, grading to dark grey. wet @ 5'

FILL - MEDIUM GRAINED, sand, some gravel, moist

FILL - COARSE GRAINED, cinders,dark grey, gravelly, trace brick, wet, grading to more brick

END OF BOREHOLE @ 12'



COMMENTS: IGLD 1985 DATUM

stratigraphy inferred from WHI-6-4S: 5' east

Gravel Pack
Concrete
Annular Seal
Water Level
Screen

waterloo hydrogeologic

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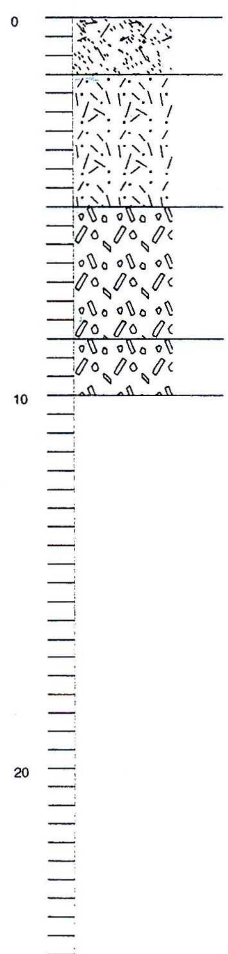
BOREHOLE N° : WHI-6-2S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 04 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 580.12	GROUT TYPE	: Bentonite
TOP OF CASING	: 579.88	DEPTH TO WATER	: 5.00 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 574.88
CO-ORDINATES	: N 2539 E 0636		



FILL - FINE GRAINED, silt, brown, sandy, moist

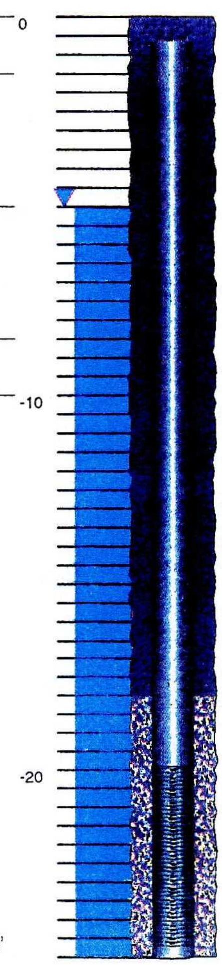
FILL - MEDIUM GRAINED, sand, grey, some gravel, moist

FILL - COARSE GRAINED, crushed limestone, light grey, granular, moist - wet

FILL - COARSE GRAINED, sand and gravel, slag-like, wet

NO RECOVERY, presumably pushing stone

END OF BOREHOLE @ 25'



COMMENTS: IGLD 1985 DATUM

attempted to re-drill in 7 different locations - refusal on concrete @ 7' in all cases

presumed to be in contact with Native Sand based on stratigraphy in neighboring boreholes.

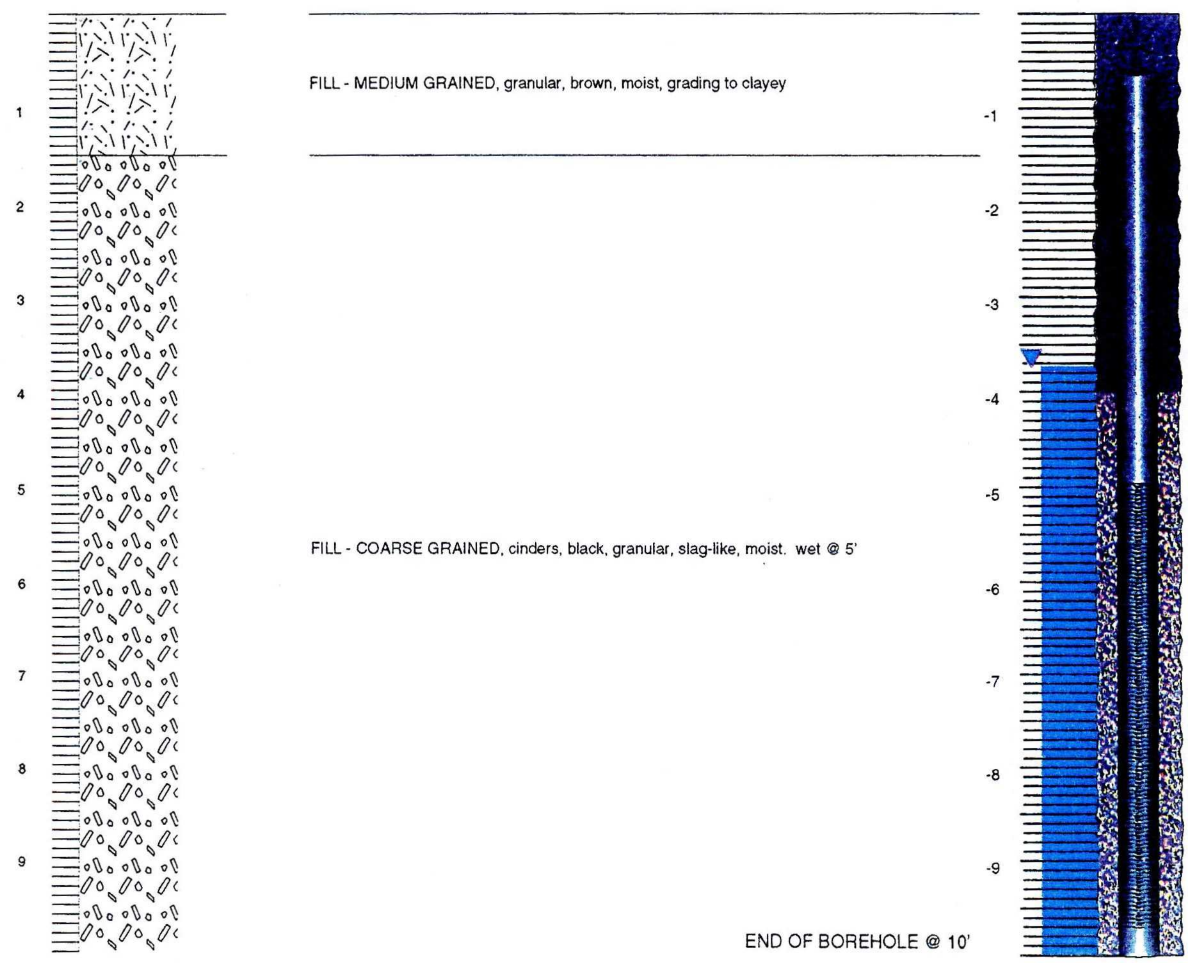
Gravel Pack
Concrete
Annular Seal
Water Level
Screen

BOREHOLE N° : WHI-6-3F

waterloo hydrogeologic
SOFTWARE · CONSULTING · TRAINING

PROJECT NUMBER	: 3010261
PROJECT NAME	: BASF - North Works
LOCATION	: Wyandotte Michigan.
DRILLING METHOD	: Soil Probe - 4.25" O.D.
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'
GROUND ELEVATION	: 580.61
TOP OF CASING	: 580.20
LOGGED BY	: D. Tamblyn
CO-ORDINATES	: N 2093 E 0491

DRILLER	: FIBERTEC
DATE DRILLED	: 01 FEB 2002
CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
GRAVEL PACK TYPE	: Silica Sand
GROUT TYPE	: Bentonite
DEPTH TO WATER	: 3.74 '
GROUND WATER ELEVATION	: 576.46



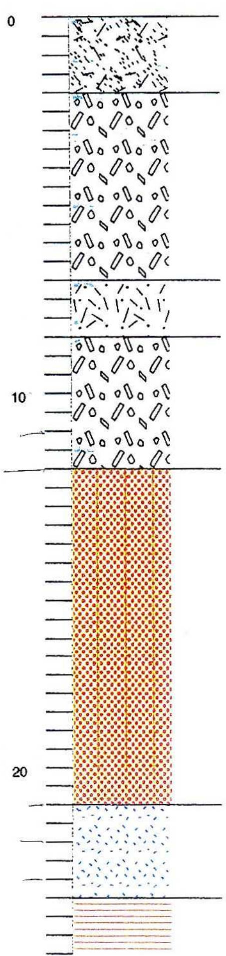
COMMENTS: IGLD 1985 DATUM
stratigraphy inferred from 6-3S: 5' northeast

Gravel Pack
Screen
Concrete
Annular Seal
Water Level

waterloo hydrogeologic
SOFTWARE • CONSULTING • TRAINING

BOREHOLE N° : WHI-6-4S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 04 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 580.91	GROUT TYPE	: Bentonite
TOP OF CASING	: 580.74	DEPTH TO WATER	: 5.93 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 574.81
CO-ORDINATES	: N 2207 E 0828		



FILL - FINE GRAINED, silt and sand, brown, clayey, moist

FILL - COARSE GRAINED, sand and gravel, grey, damp, grading to dark grey. wet @ 5'

FILL - MEDIUM GRAINED, sand, some gravel, moist

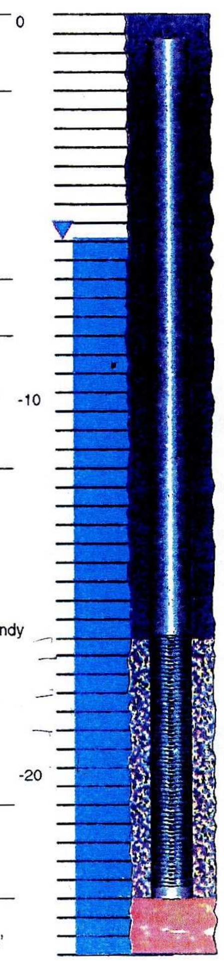
FILL - COARSE GRAINED, cinders,dark grey, gravelly, trace brick, wet, grading to more brick

SILT, grey, sandy, some clay, trace gravel, soft, wet. no organics, grading to very soft, less sandy

FINE SAND, grey, silty, trace to some clay, soft, wet

CLAY, grey, sandy, silty, soft, wet

END OF BOREHOLE @ 25'



COMMENTS: IGLD 1985 DATUM

see also WHI-6-4F: 5' west

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

waterloo hydrogeologic

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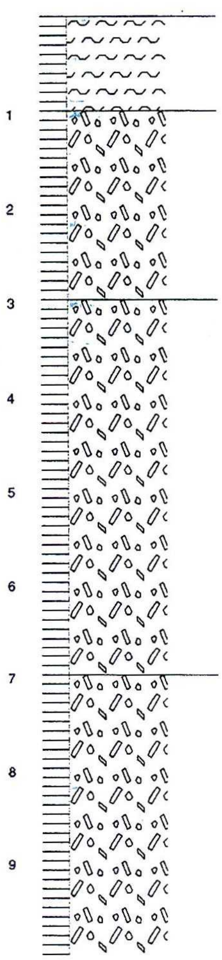
BOREHOLE N° : WHI-6-5F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 01 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 579.82	GROUT TYPE	: Bentonite
TOP OF CASING	: 579.32	DEPTH TO WATER	: 2.81 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 576.51
CO-ORDINATES	: N 1928 E 0734		



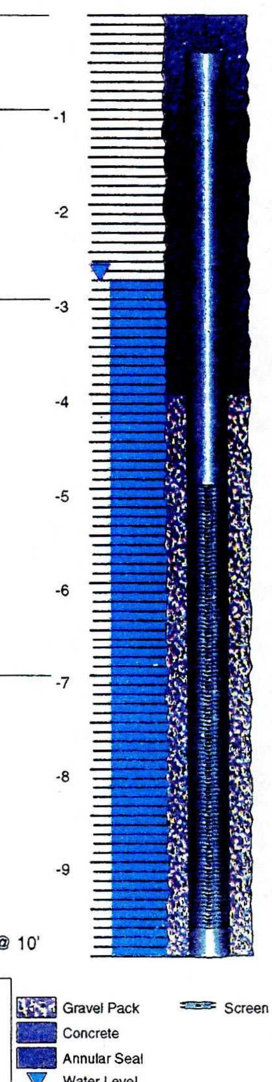
TOPSOIL, brown, sandy, silty, moist. no grass.

FILL - COARSE GRAINED, sand and gravel, grey, silty, very dense, moist

FILL - COARSE GRAINED, coarse gravel, grey, wet

FILL - COARSE GRAINED, slag, black, wet

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM

stratigraphy inferred from WHI-6-5S: 4' east

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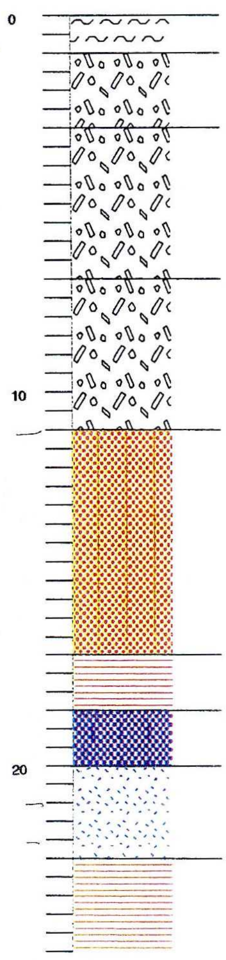
BOREHOLE N° : WHI-6-5S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 01 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 579.75	GROUT TYPE	: Bentonite
TOP OF CASING	: 579.60	DEPTH TO WATER	: 3.13 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 576.47
CO-ORDINATES	: N 1927 E 0738		



TOPSOIL, brown, sandy, silty, moist. no grass.

FILL - COARSE GRAINED, sand and gravel, grey, silty, very dense, moist

FILL - COARSE GRAINED, coarse gravel, grey, wet

FILL - COARSE GRAINED, slag, black, wet

SILT, grey, trace sand, trace clay, trace organics, soft, wet.
fewer organics 13'-15', grading to some sand and organics

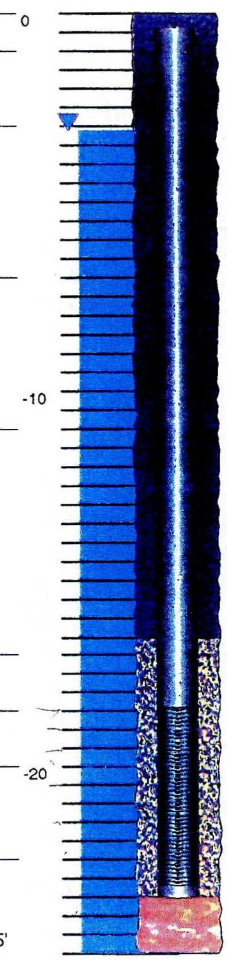
CLAY, blue, sandy, silty, firm, wet

SAND AND SILT, grey, soft, wet

FINE SAND, wet

CLAY, grey, soft, wet

END OF BOREHOLE @ 25'



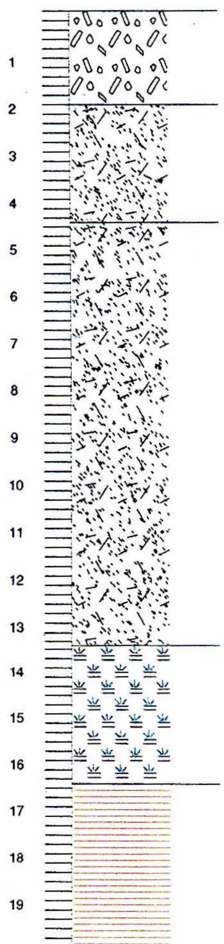
COMMENTS: IGLD 1985 DATUM
see also WHI-6-5F: 4' west

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

waterloo hydrogeologic
SOFTWARE • CONSULTING • TRAINING

BOREHOLE N° : WHI-7-1F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 29 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 581.14	GROUT TYPE	: Bentonite
TOP OF CASING	: 580.90	DEPTH TO WATER	: -0.01 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 580.91
CO-ORDINATES	: N 1251 E 1145		



FILL - COARSE GRAINED, sand and gravel, dark grey, moist - wet

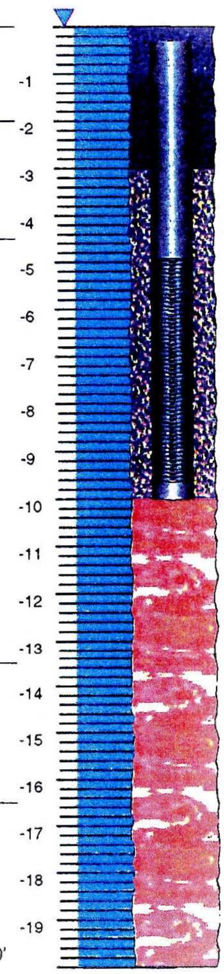
FILL - FINE GRAINED, silt, bright orange-rust, clayey, wet

FILL - FINE GRAINED, DBO and lime waste, white to light grey, wet. not cohesive.

PEAT, brown, silty, clayey, wet

CLAY, blue, some organics, wet. grading to mottled grey-brown, no organics

END OF BOREHOLE @ 20'



COMMENTS: IGLD 1985 DATUM

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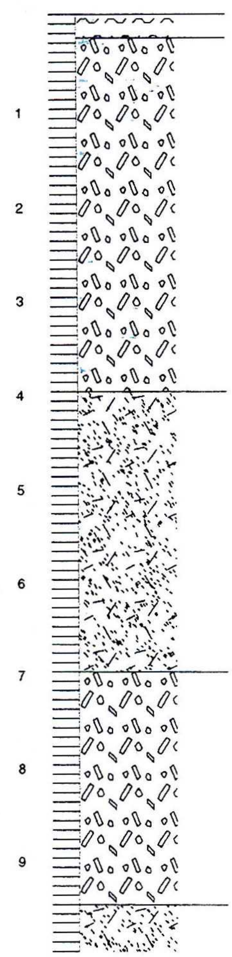
BOREHOLE N° : WHI-7-2F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 29 JAN 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 582.23	GROUT TYPE	: Bentonite
TOP OF CASING	: 581.81	DEPTH TO WATER	: -0.01 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 581.82
CO-ORDINATES	: N 0761 E1276		



TOPSOIL, poor grass cover

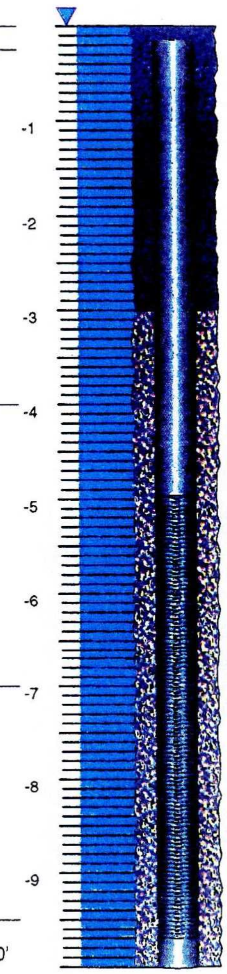
FILL - COARSE GRAINED, sand and gravel, black, moist

FILL - FINE GRAINED, DBO, white, pasty, moist - wet

FILL - COARSE GRAINED, sand and gravel, brown, black, and grey layers, wet

FILL - FINE GRAINED, DBO, white, pasty, moist-wet

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Annular Seal
Water Level
Screen

waterloo hydrogeologic
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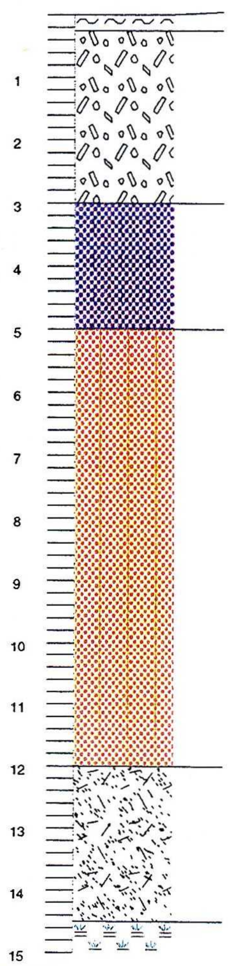
BOREHOLE N° : WHI-7-3F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 29 JAN 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 583.13	GROUT TYPE	: Bentonite
TOP OF CASING	: 582.69	DEPTH TO WATER	: 3.02 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 579.67
CO-ORDINATES	: N 0302 E 1424		



TOPSOIL, moist

FILL - COARSE GRAINED, sand and gravel, light grey, silty

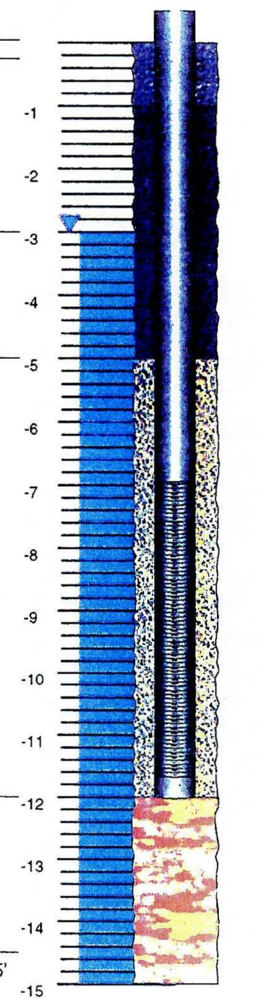
SAND AND SILT - FILL - grey, trace clay, firm, moist - wet

SILT - FILL - grey, sandy, trace clay, wet, grading to very loose

FILL - FINE GRAINED, DBO, white, pasty, grading coarser

PEAT, black, silty, wet. swampy odor

END OF BOREHOLE @ 15'



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

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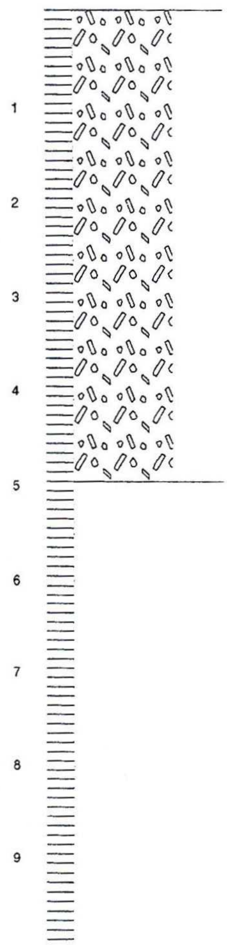
BOREHOLE N° : WHI-7-4F

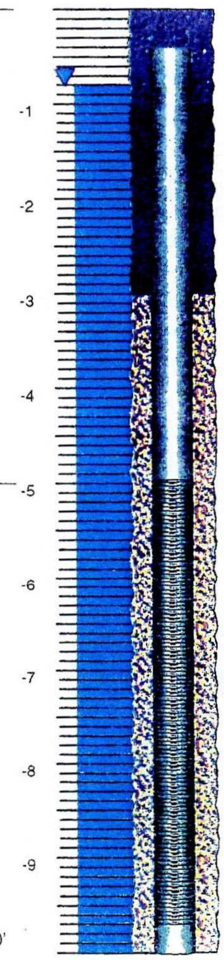
PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 29 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 584.20	GROUT TYPE	: Bentonite
TOP OF CASING	: 583.81	DEPTH TO WATER	: 0.81 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 583.00
CO-ORDINATES	: N 0479 E 1106		



FILL - COARSE GRAINED, sand and gravel, dark grey, some silt, moist, grading light grey

NO RECOVERY, possibly pushing stone or concrete, very loose, wet

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM
stratigraphy inferred from WHI-7-4P: 3' south

Gravel Pack
Concrete
Annular Seal
Water Level
Screen

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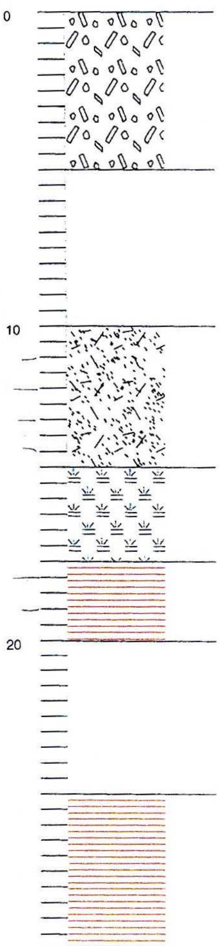
BOREHOLE N° : WHI-7-4P

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 29 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 584.17	GROUT TYPE	: Bentonite
TOP OF CASING	: 583.80	DEPTH TO WATER	: 0.69 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 583.11
CO-ORDINATES	: N 0476 E 1107		



FILL - COARSE GRAINED, sand and gravel, dark grey, some silt, moist, grading light grey

NO RECOVERY, very loose, wet

FILL - FINE GRAINED, DBO, white, pasty, wet

PEAT, dark grey, fibrous, moist

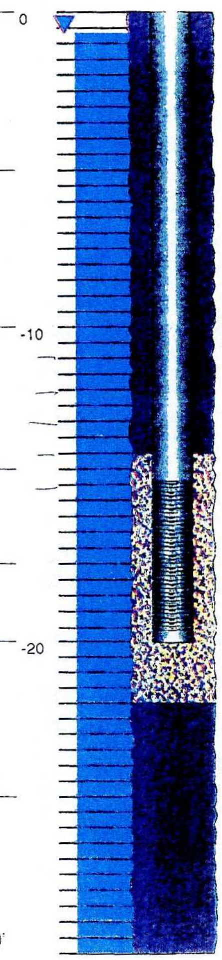
CLAY, brown, organics, wet

NO RECOVERY

CLAY, blue, trace sand, wet, grading to mottled grey-brown, moist

1' medium sand lenses @ 29' and 29.5'

END OF BOREHOLE @ 30'



COMMENTS: IGLD 1985 DATUM
see also WHI-7-4F: 3' north

Gravel Pack
Concrete
Annular Seal
Water Level
Screen

waterloo hydrogeologic
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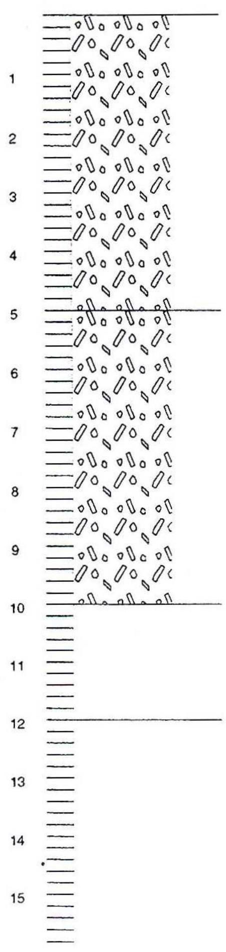
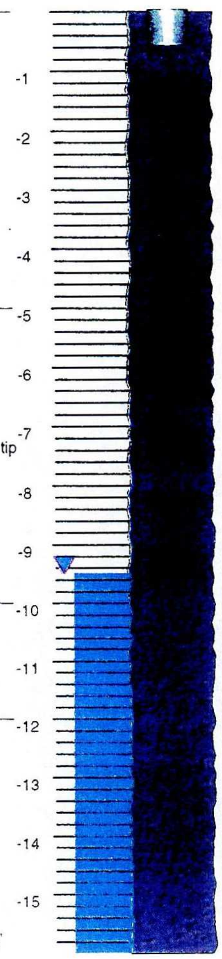
BOREHOLE N° : WHI-8-1X

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 29 JAN 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: n/a
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: n/a
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: n/a
GROUND ELEVATION	: 577.81	GROUT TYPE	: Bentonite
TOP OF CASING	: n/a	DEPTH TO WATER	: 9.5 ' ±
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: n/a
CO-ORDINATES	: S 0298 E 1685		



Depth	Description	Elevation
0 – 5	FILL - COARSE GRAINED, sand and gravel, brown-black-grey, damp. 6 distinct layers.	-1 to -5
5 – 10	FILL - COARSE GRAINED, same as above, very hard, possibly concrete. wet @9.5', wood in tip	-5 to -10
10 – 12	NO RECOVERY	-10 to -12
12 – 16	VOID	-12 to -15

END OF BOREHOLE @ 16'



COMMENTS: IGLD 1985 DATUM

No well installed. Void presumed to be due to wave action eroding soil between oak piles.

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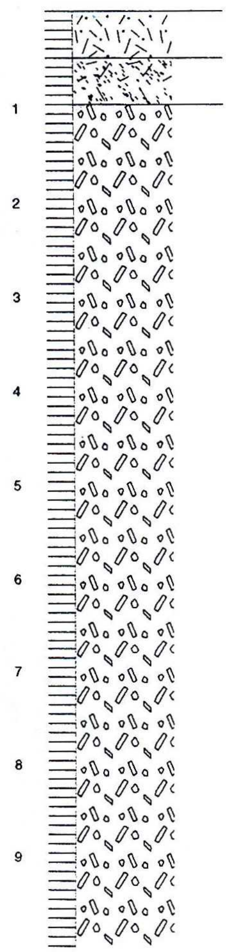
BOREHOLE N° : WHI-8-2F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 29 JAN 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 578.24	GROUT TYPE	: Bentonite
TOP OF CASING	: 577.83	DEPTH TO WATER	: 5.06 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 572.77
CO-ORDINATES	: S 0891 E 1572		

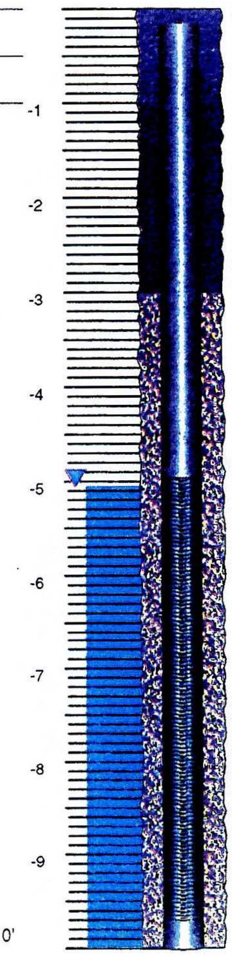


FILL - MEDIUM GRAINED, sand

FILL - FINE GRAINED, clay, brown, wet

FILL - COARSE GRAINED,fine sand and gravel, moist. wet @7.5'. grading black, coarse.

END OF BOREHOLE @ 10'



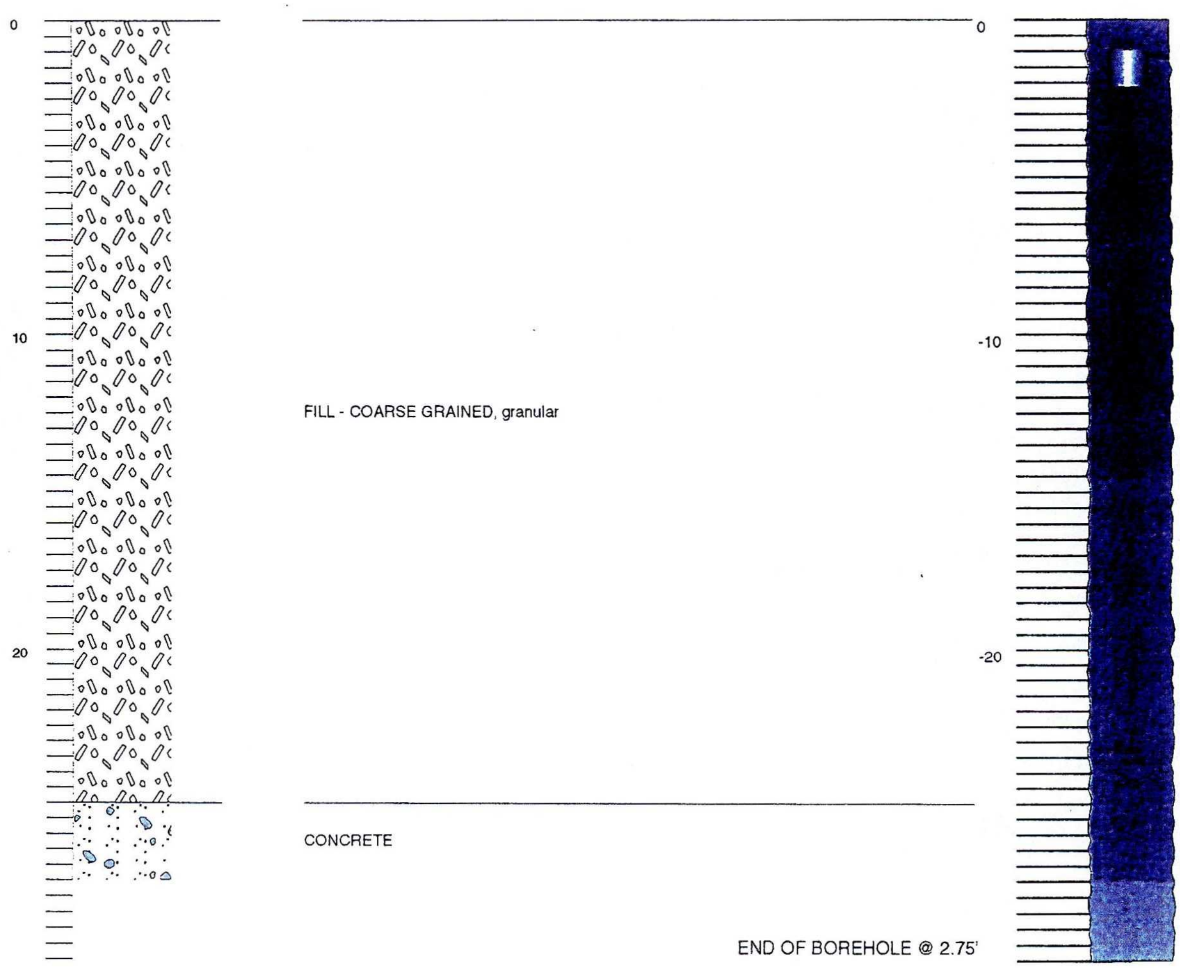
COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

waterloo hydrogeologic
SOFTWARE • CONSULTING • TRAINING

BOREHOLE N° : WHI-9-1X

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 30 JAN 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: n/a
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: n/a
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: n/a
GROUND ELEVATION	: 577.96	GROUT TYPE	: Bentonite
TOP OF CASING	: n/a	DEPTH TO WATER	: n/a
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: n/a
CO-ORDINATES	: S 0240 E 1267		



COMMENTS: IGLD 1985 DATUM
Probe refusal on concrete at 2.75'. Also refusal at locations 15' southwest and 30' southwest

Annular Seal

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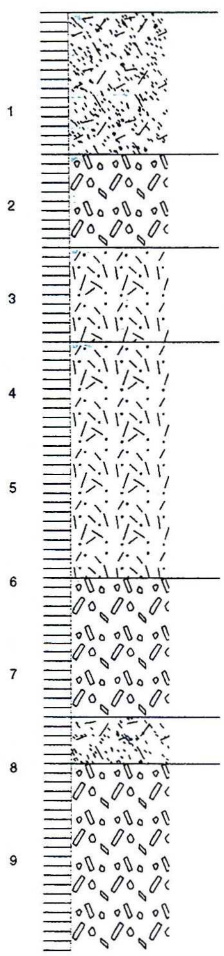
BOREHOLE N° : WHI-9-1F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 07 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 577.23	GROUT TYPE	: Bentonite
TOP OF CASING	: 576.97	DEPTH TO WATER	: 2.05 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 574.92
CO-ORDINATES	: S 0287 E 1054		



FILL - FINE GRAINED, clay, brown, silty, some gravel, moist

FILL - COARSE GRAINED, sand and gravel, dark grey, silty, moist. wet @ 2.3'

FILL - MEDIUM GRAINED, lime waste and cinders, grey-brown, wet

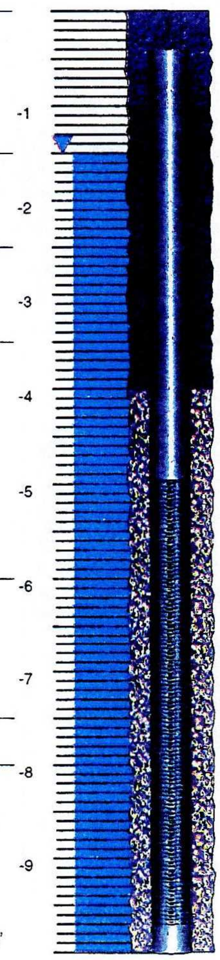
FILL - MEDIUM GRAINED, lime waste, white - light grey, wet. consistency similar to sand

FILL - COARSE GRAINED, slag, dark grey, silty, wet

FILL - FINE GRAINED, lime waste and DBO, white, wet. consistency similar to silt

FILL - COARSE GRAINED

END OF BOREHOLE @ 10'



COMMENTS: IGLD 1985 DATUM
stratigraphy inferred from WHI-9-1S 4' south

Gravel Pack
Screen
Concrete
Annular Seal
Water Level

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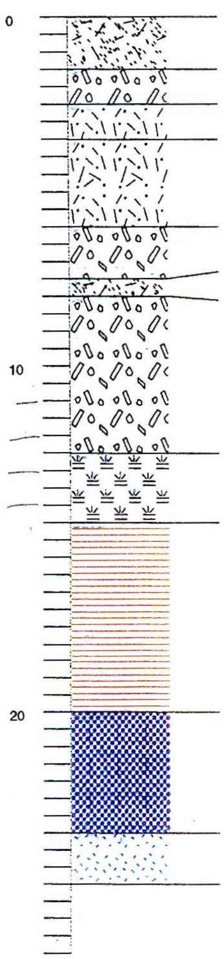
BOREHOLE N° : WHI-9-1S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 07 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 577.33	GROUT TYPE	: Bentonite
TOP OF CASING	: 577.11	DEPTH TO WATER	: 2.39 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 574.72
CO-ORDINATES	: S 0291 E 1053		



FILL - FINE GRAINED, clay, brown, silty, some gravel, moist

FILL - COARSE GRAINED, sand and gravel, dark grey, silty, moist. wet @ 2.3'

FILL - MEDIUM GRAINED, lime waste and cinders, grey-brown, wet

FILL - MEDIUM GRAINED, lime waste, white - light grey, wet. consistency similar to sand

FILL - COARSE GRAINED, slag, dark grey, silty, wet

FILL - FINE GRAINED, lime waste and DBO, white, wet. consistency similar to silt

FILL - COARSE GRAINED, slag, kark grey, wet

PEAT, dark brown, occasional wood fragments, moist-wet,grading to ORGANIC SILT, brown

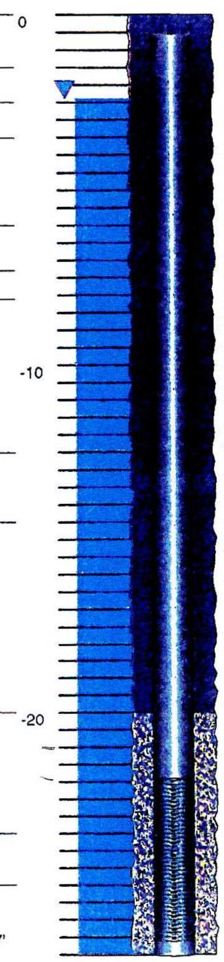
CLAY, grey-brown, silty, trace to some sand, trace organics, very soft, wet

SAND AND SILT, grey-brown, trace organics, very soft, wet

FINE SAND, grey, silty to some silt, wet

NO RECOVERY

END OF BOREHOLE @ 27'



COMMENTS: IGLD 1985 DATUM

See also WHI-9-1F: 4' north

Borehole was not advanced further due to risk of probe jamming.

Gravel Pack
Concrete
Annular Seal
Water Level
Screen

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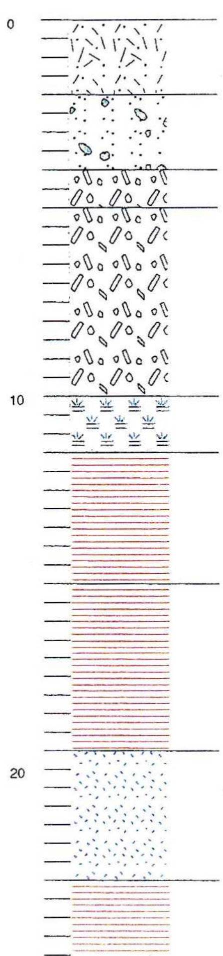
BOREHOLE N° : WHI-9-2S

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 30 JAN 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 576.78	GROUT TYPE	: Bentonite
TOP OF CASING	: 576.46	DEPTH TO WATER	: 1.79 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 574.67
CO-ORDINATES	: S 0649 E 1205		



FILL - MEDIUM GRAINED, sand, brown, wet

CONCRETE, decayed, wet

FILL - COARSE GRAINED, brown, granular, wet

FILL - COARSE GRAINED, gravel, dark grey, some stones, wet

PEAT, dark brown, clayey, some wood fragments, soft, wet

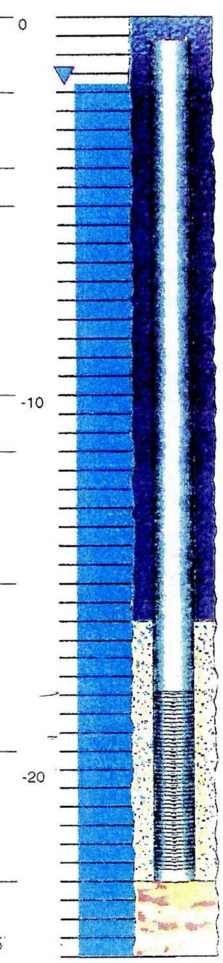
CLAY, dark brown, many organics, soft, wet

CLAY, blue, firm, wet

FINE SAND, brown, some silt, wet, grading grey

CLAY, grey, sandy, very soft, wet

END OF BOREHOLE @ 25'



COMMENTS: IGLD 1985 DATUM

Probe refusal on concrete at 4' to 6' depth at 12 nearby locations

see also WHI-9-2F: 17' north

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

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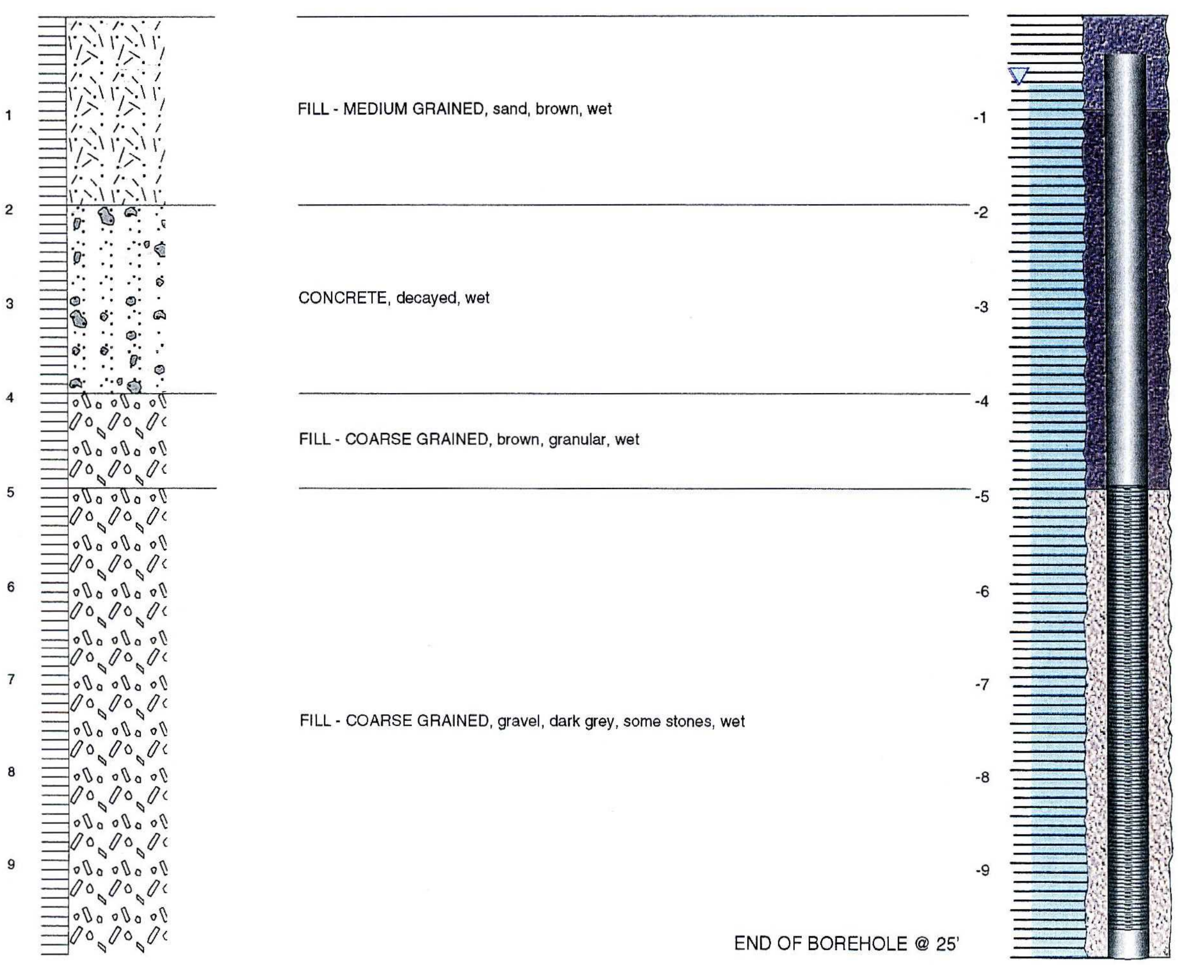
BOREHOLE N° : WHI-9-2F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 30 JAN 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 576.81	GROUT TYPE	: Bentonite
TOP OF CASING	: 576.54	DEPTH TO WATER	: 0.74 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 575.80
CO-ORDINATES	: S 0632 E 1206		



COMMENTS: IGLD 1985 DATUM

Probe deflected approx. 10 degrees off-vertical

Sand pack bridged at unknown depth. Original 25' BH used for 10' well. See WHI-9-2S: 17' south

Gravel Pack
Concrete
Annular Seal
Water Level
Screen

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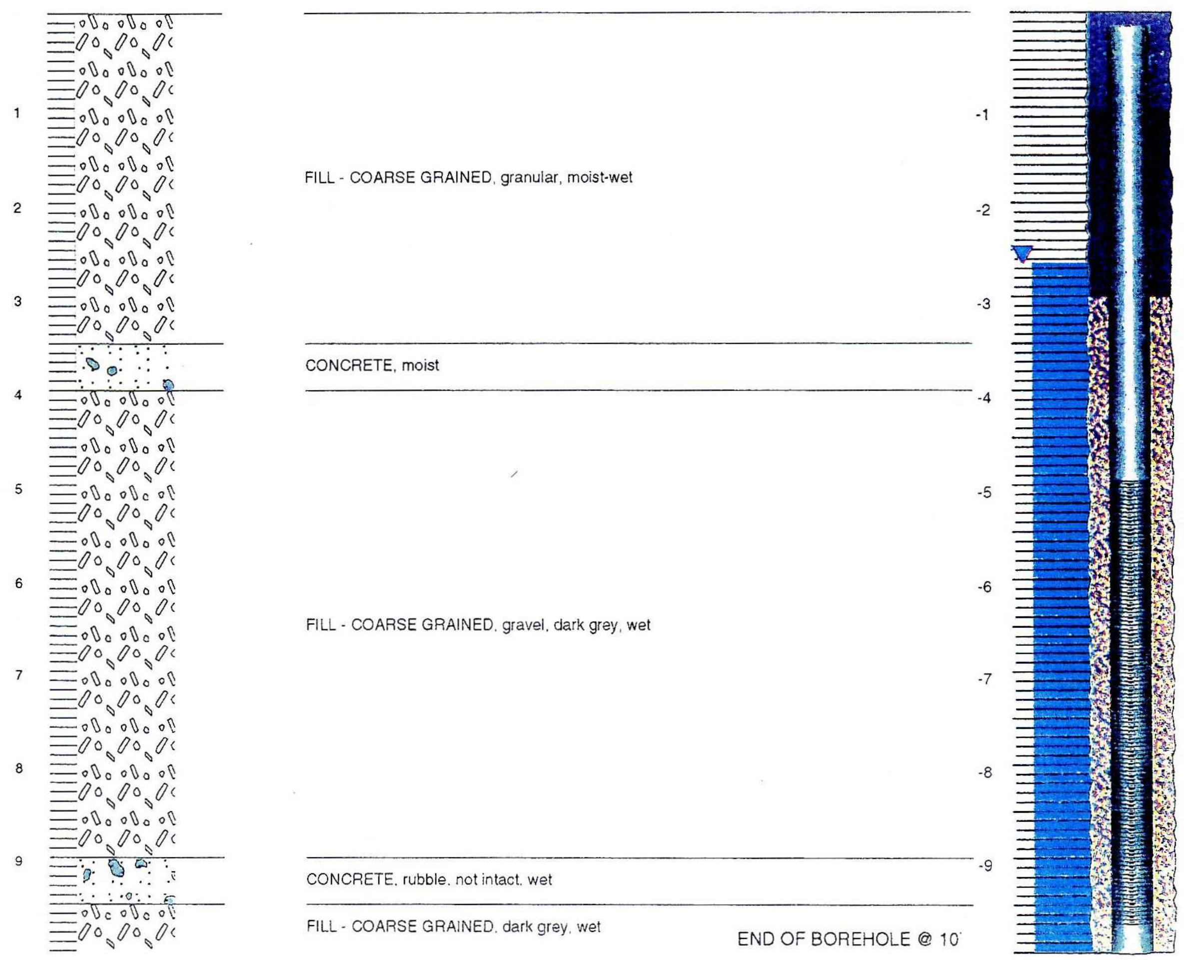
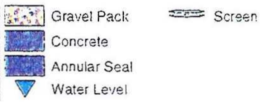
BOREHOLE N° : WHI-9-3F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 30 JAN 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 578.15	GROUT TYPE	: Bentonite
TOP OF CASING	: 577.74	DEPTH TO WATER	: 2.65 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 575.09
CO-ORDINATES	: S 0891 E 1075		



COMMENTS: IGLD 1985 DATUM

Probe refusal on concrete at 3.5' at 10 nearby locations.



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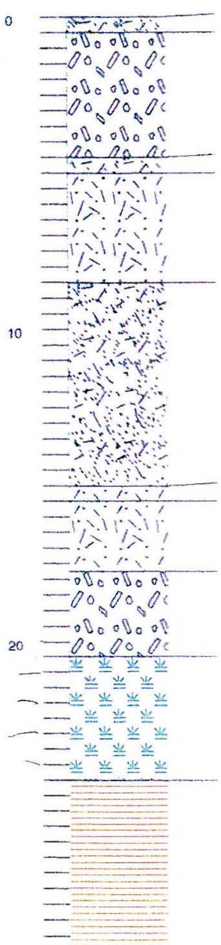
BOREHOLE N° : WHI-9-4F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 30 JAN 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 578.62	GROUT TYPE	: Bentonite
TOP OF CASING	: 578.28	DEPTH TO WATER	: 2.88 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 575.40
CO-ORDINATES	: S 1161 E 1000		



FILL - FINE GRAINED, clayey, brown, moist

FILL - COARSE GRAINED, sand and gravel, dark grey, moist, trending to wet

FILL - FINE GRAINED, consistency similar to DBO, yellowish, wet

FILL - MEDIUM GRAINED, sandy, grey, granular, loose, wet. wood fragments @ 7.5'

FILL - FINE GRAINED, silty, sandy, grey, loose, grading soft, odor, unknown composition

FILL - MEDIUM GRAINED, sandy, silty, grey, moist

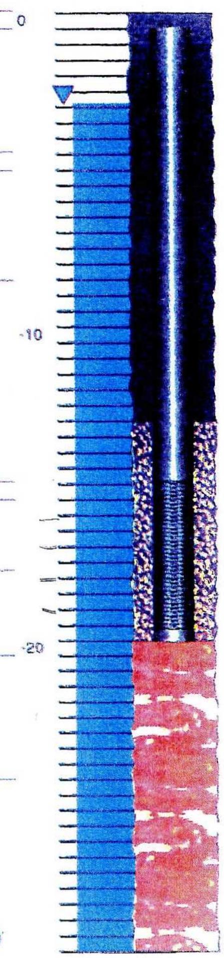
FILL - MEDIUM GRAINED, silt slurry, grey, very soft to liquified, wet

FILL - COARSE GRAINED, lime waste and slag, wet

PEAT, dark brown, soft, trending to ORGANIC SILT, clayey, soft, wet

CLAY, brown, silty, trace sand and gravel, soft, wet, grading grey, increasing plasticity

END OF BOREHOLE @ 30'



COMMENTS: IGLD 1985 DATUM

Gravel Pack
Concrete
Native soil
Annular Seal
Water Level
Screen

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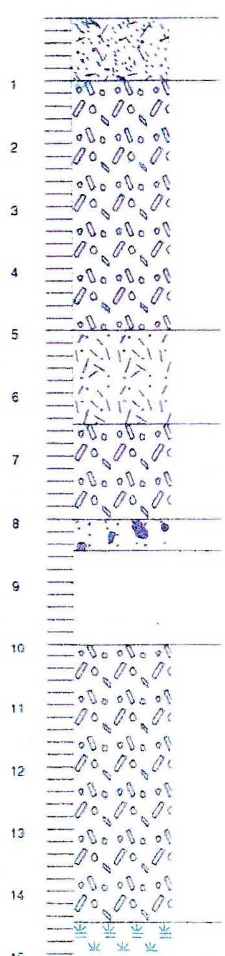
BOREHOLE N° : WHI-9-5F

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 01 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 577.83	GROUT TYPE	: Bentonite
TOP OF CASING	: 577.39	DEPTH TO WATER	: 2.15 '
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: 575.24
CO-ORDINATES	: S 1332 E 0931		



FILL - FINE GRAINED, clayey, grey, wet

FILL - COARSE GRAINED, granular, slag, occasional seams of cinders and lime waste, silty, wet

FILL - MEDIUM GRAINED, fine granular lime waste, white - light grey, wet

FILL - COARSE GRAINED, slag and brick fragments, red-brown,

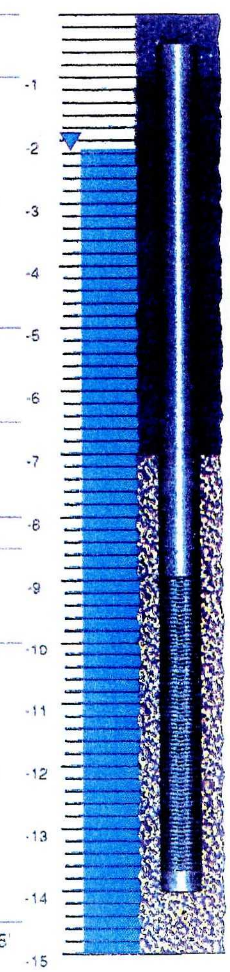
CONCRETE, degraded, wet

NO SAMPLE - solid bore

FILL - COARSE GRAINED, slag, dark grey, granular, occasional seams of DBO and silt, wet

PEAT, black, silty, some sand, trace fine rootlets, wet

END OF BOREHOLE @ 15'



COMMENTS: IGLD 1985 DATUM

Probe refusal on CONCRETE @ 8.25' - continue BH 15' to North - solid bore to 10' depth

Gravel Pack
Screen
Concrete
Annular Seal
Water Level

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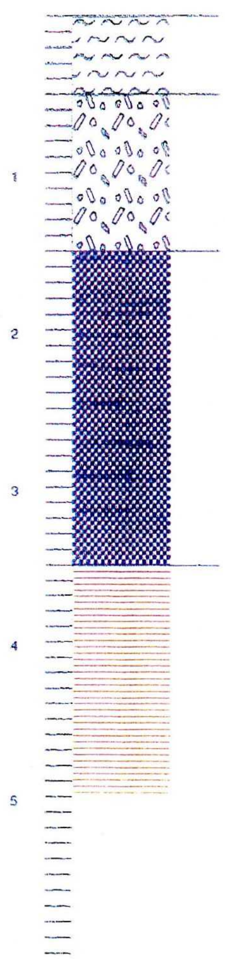
BOREHOLE N° : RP-35-N

PROJECT NUMBER	: 3010261	DRILLER	: FIBERTEC
PROJECT NAME	: BASF - North Works	DATE DRILLED	: 06 FEB 2002
LOCATION	: Wyandotte Michigan.	CASING TYPE / DIAMETER	: Sch. 40 PVC 1" I.D.
DRILLING METHOD	: Soil Probe - 4.25" O.D.	SCREEN TYPE / SLOT	: Sch 40 PVC / 0.010" Slot
SAMPLING METHOD	: Dual Tube Sampling System - 1.25" x 5'	GRAVEL PACK TYPE	: Silica Sand
GROUND ELEVATION	: 578.11	GROUT TYPE	: Bentonite
TOP OF CASING	: 577.74	DEPTH TO WATER	: n/a
LOGGED BY	: D. Tamblyn	GROUND WATER ELEVATION	: n/a
CO-ORDINATES	: S 2134 W 0289		

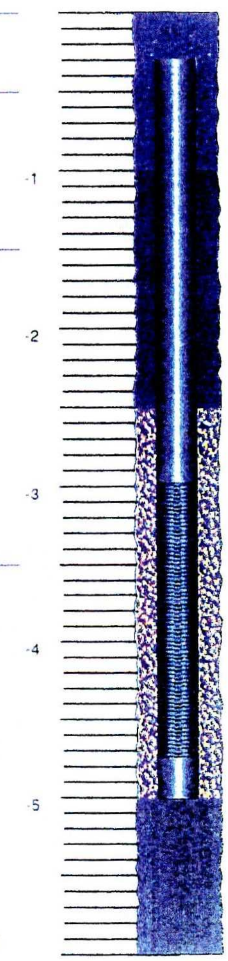


SOIL

FILL - COARSE GRAINED, cinders, black

MEDIUM SAND, yellow

CLAY, brown, stiff



END OF BOREHOLE @ 5'

COMMENTS: IGLD 1985 DATUM
Stratigraphy inferred from piezometer for P-35-N: 14' south
Piezometer did not contain water when monitored 08 Feb 2002.

Gravel Pack
Concrete
Annular Seal
Screen

APPENDIX C – TABLES

Table 1. Piezometer Installation Data

PIEZOMETER LOCATIONS	SITE COORDINATES [1] North / South	East / West	ELEV TOP WELL [1,2]	GROUND ELEV [1]	BOTTOM WELL INSTALLED [3]	BOTTOM WELL MONITORED [4]	DISCREP-ANCY [5]	ELEV BOTTOM WELL	SCREEN LENGTH	INSTALL DATE	NOTES
	feet	feet	feet	feet	feet	feet	feet	feet	feet		
13X	S 2963	W 0244		579.91							Probe refusal on CONCRETE.
22X	S 2263	W 0423		582.02							Probe refusal on CONCRETE.
62X	S 2536	E 0607		580.23							Probe refusal on CONCRETE.
81X	N 0298	E 1685		577.81							Probe refusal on CONCRETE.
91X	N 0240	E 1267		577.96							Probe refusal on CONCRETE.
93X	N 0897	E 1110		577.85							Probe refusal on CONCRETE.
WHI-1-2S	N 2831.66	W 0036.65	581.56	581.68	17.0	16.56	0.44	565.0	4.0	5 Feb 2002	
WHI-1-3S	N 2911.13	W 0259.81	579.77	580.01	14.0	13.04	0.96	566.73	5.0	5 Feb 2002	log not adjusted
WHI-2-1S	N 2032.01	W 0667.89	584.49	584.72	8.0	7.7	0.3	576.79	4.0	7 Feb 2002	
WHI-2-2S	N 2233.07	W 0439.60	581.71	581.93	10.0	9.67	0.33	572.04	5.0	5 Feb 2002	silty 3.5m E of pavement
WHI-2-3S	N 2430.44	W 0646.68	583.20	583.50	6.0	5.85	0.15	577.35	3.0	7 Feb 2002	
WHI-3-1S	N 1366.22	W 0708.56	583.50	583.68	7.0	5.99	[illegible]	577.51	3.0	6 Feb 2002	log adjusted per monitoring
WHI-3-2S	N 0954.02	W 0452.36	581.28	581.49	6.0	5.63	0.37	575.65	3.0	5 Feb 2002	
WHI-3-3S	N 0716.83	W 0752.79	584.95	585.20	7.5	7.37	0.13	577.58	4.0	6 Feb 2002	
WHI-4-1S	S 0886.08	W 0442.45	577.98	578.14	9.0	8.68	0.32	569.3	5.0	6 Feb 2002	silty
WHI-4-2S	S 1384.72	W 0584.08	577.67	577.95	6.0	5.57	0.43	572.1	3.0	6 Feb 2002	
WHI-5-1F	S 2161.29	E 0874.42	575.74	576.16	10.0	9.35	0.65	566.39	5.0	6 Feb 2002	silty, log not adjusted
WHI-5-1S	S 2161.93	E 0877.47	575.61	576.15	25.0	22.79	[illegible]	552.82	5.0	1 Feb 2002	v. silty 2m E of 5.1F, log adjusted per monitoring
WHI-5-2F	S 2043.34	E 0470.38	577.27	577.47	5.0	4.44	0.56	572.83	2.0	6 Feb 2002	v. silty, log not adjusted
WHI-5-2S	S 2046.84	E 0470.67	577.07	577.40	15.0	14.52	0.48	562.55	5.0	6 Feb 2002	rotten egg odor, 1m S of 5.2F
WHI-6-1F	N 2867.76	E 0446.13	578.10	578.31	10.0	9.79	0.21	568.31	5.0	4 Feb 2002	no name plate
WHI-6-1S	N 2868.54	E 0449.05	578.16	578.28	20.0	19.09	0.91	559.07	5.0	4 Feb 2002	1m E of 6-1F, log not adjusted
WHI-6-2S	N 2539.18	E 0636.35	579.88	580.12	25.0	24.46	0.54	555.42	5.0	4 Feb 2002	log not adjusted
WHI-6-3F	N 2093.15	E 0491.22	580.20	580.61	10.0	9.91	0.09	570.29	5.0	1 Feb 2002	
WHI-6-3S	N 2097.02	E 0494.43	580.20	580.77	20.0	19.65	0.35	560.55	5.0	1 Feb 2002	1m N of 6-3F
WHI-6-4F	N 2206.59	E 0827.57	580.72	580.84	12.0	11.8	0.2	568.92	5.0	1 Feb 2002	
WHI-6-4S	N 2204.78	E 0823.28	580.74	580.91	23.5	22.96	0.54	557.78	5.0	4 Feb 2002	2m W of 6-4F, log not adjusted
WHI-6-5F	N 1927.85	E 0734.37	579.32	579.82	10.0	9.71	0.29	569.61	5.0	1 Feb 2002	
WHI-6-5S	N 1926.78	E 0737.74	579.60	579.75	23.5	23.19	0.31	556.41	5.0	1 Feb 2002	1m E of 6-5F
WHI-7-1F	N 1251.39	E 1145.35	580.90	581.14	10.0	9.86	0.14	571.04	5.0	29 Jan 2002	slip cap - flowing
WHI-7-2F	N 0761.01	E 1276.13	581.81	582.23	10.0	9.59	0.41	572.22	5.0	29 Jan 2002	slip cap - flowing
WHI-7-3F	N 0302.25	E 1424.11	582.69	583.13	12.0	11.39	0.61	571.3	5.0	29 Jan 2002	slip cap, log not adjusted
WHI-7-4F	N 0479.06	E 1105.56	583.81	584.20	10.0	9.91	0.09	573.9	5.0	29 Jan 2002	slip cap, water in casing
WHI-7-4P	N 0475.92	E 1106.70	583.80	584.17	19.5	19.57	- 0.07	564.23	5.0	29 Jan 2002	slip cap

PIEZOMETER LOCATIONS	SITE COORDINATES[1] North / South	East / West	ELEV TOP WELL[1,2]	GROUND ELEV[1]	BOTTOM WELL INSTALLED[3]	BOTTOM WELL MONITORED[4]	DISCREP-ANCY[5]	ELEV BOTTOM WELL	SCREEN LENGTH	INSTALL DATE	NOTES
	feet	feet	feet	feet	feet	feet	feet	feet	feet		
WHI-8-2F	S 0891.15	E 1572.48	577.83	578.24	10.0	9.73	0.27	568.1	5.0	29 Jan 2002	slip cap
WHI-9-1F	S 0287.27	E 1053.59	576.97	577.23	10.0	10.14	- 0.14	566.83	5.0	7 Feb 2002	
WHI-9-1S	S 0290.97	E 1052.62	577.11	577.33	27.0	26.52	0.48	550.59	5.0	7 Feb 2002	area flooded, 1m S of 9-1F
WHI-9-2F	S 0631.53	E 1205.64	576.54	576.81	10.0	8.35	[redacted]	568.19	5.0	30 Jan 2002	screw cap, no concrete, log adjusted per monitoring
WHI-9-2S	S 0649.21	E 1204.68	576.46	576.78	22.5	22.34	0.16	554.12	5.0	30 Jan 2002	6m S of 9-2F - slip cap, no concrete, silty
WHI-9-3F	S 0891.48	E 1075.03	577.74	578.15	10.0	9.63	0.37	568.11	5.0	30 Jan 2002	silty, slip cap
WHI-9-4F	S 1161.41	E 1000.19	578.28	578.62	15.0	14.62	0.38	563.66	5.0	30 Jan 2002	
WHI-9-5F	S 1331.59	E 0931.04	577.39	577.83	14.0	13.93	0.07	563.46	5.0	1 Feb 2002	
RP-35-N	S 2134.37	W 0289.11	577.74	578.11	5.0	4.93	0.07	572.81	2.0	6 Feb 2002	Replaces P-35-N which was left in place (damaged).
South Wall - Perry Place	N 3120.46	E 0326.46		576.98							For monitoring water levels in the Detroit River.
South Marina - Mulberry St.	S 2342.39	E 0819.41		575.99							For monitoring water levels in the Detroit River

NOTES:
1 SURVEYED BY URBAN ENGINEERING MARCH 2002
2 TOP WELL = top of highest point or marked point on 1" diameter PVC piezometer
3 BOTTOM WELL INSTALLED = depth from ground surface as recorded on drilling log
4 BOTTOM WELL MONITORED = depth from ground surface as recorded during monitoring
5 DISCREPANCY = BOTTOM WELL INSTALLED - BOTTOM WELL MONITORED. For discrepancies greater than 1.0 feet, the BH log was adjusted to reflect the monitored depth.
6 ELEV BOTTOM WELL = GROUND - BOTTOM WELL MONITORED; bottom screen is 0.25' higher
7 PIEZOMETER LOCATIONS designated "X" are boreholes only without piezometer. Their co-ordinates are only approximate.

Table 2. Survey Data for Existing Monitoring Wells

Piezometer	SITE COORDINATES [1] North / South	SITE COORDINATES [1] East / West	ELEV TOP WELL [1]	GROUND ELEV [1]	PREVIOUS TOP WELL [2]	PREVIOUS GROUND ELEV [2]	Δ TW [3]	Δ GRND [3]	Δ WL [4]	NOTES
	feet	feet	feet	feet	feet	feet	feet	feet	feet	
[redacted]	S 1445.44	E 1275.44	576.77	577.14	579.81	577.19	[redacted]	– 0.05		cut down to flush mount, stamped P7N, marked CMS-MW-10 on concrete pad
CMS-MW-12			579.55	576.91	579.43	577.01	+ 0.12	– 0.10	+ 0.12	
[redacted]			577.62	577.77	580.66	577.86	[redacted]	– 0.09		marked as P10N, cut down to flush mount, bentonite swollen
CMS-MW-5			583.93	581.5	583.91	581.57	+ 0.02	– 0.07	+ 0.02	
CMS-MW-6			588.21	586.68	588.19	586.45	+ 0.02	+ 0.23	+ 0.02	
CMS-MW-7			580.57	578.34	580.57	578.4	+ 0.00	– 0.06	+ 0.00	
CMS-MW-8			579.92	577.4	579.9	577.33	+ 0.02	+ 0.07	+ 0.02	
[redacted]	S 1154.57	E 1288.42	577.93	578.22	580.85	578.31	[redacted]	– 0.09		cut down to flush mount, v.v. silty
DNR-2			583.5	583.21	584.23	583.38	– 0.73	– 0.17		0.8 ft top with lock, knocked off
GTI-PW-1			583.34	580.72	583.29	580.58	+ 0.05	+ 0.14	+ 0.05	indistinct WL signal
GTI-TMW-1			584.5	582.88	584.59	582.23	– 0.09	+ 0.65	– 0.09	(Leans East)
GTI-TMW-2			584.64	582.85	584.45	582.75	+ 0.19	+ 0.10	+ 0.19	
GTI-TMW-3			582.71	580.29	582.35	579.61	+ 0.36	+ 0.68	+ 0.56	
GTI-TMW-4			582.58	579	578.62	578.62	[redacted]	+ 0.38	[redacted]	well stick-up not recorded previously
GTI-TMW-5			582.17	579.84	581.79	579.93	+ 0.38	– 0.09	+ 0.38	(Leans Southeast), bent
P-11-N			576.69	574.68	576.68	574.76	+ 0.01	– 0.08	+ 0.01	surface flooded
P-15-N			578.4	576.2	578.37	576.1	+ 0.03	+ 0.10	+ 0.03	
P-16-N			587.63	585.38	587.63	585.36	+ 0.00	+ 0.02	+ 0.00	silty
P-1-NA			581.2	579.31	581.2	579.07	+ 0.00	+ 0.24	+ 0.00	
P-1-NB			576.84	576.57	576.89	576.49	– 0.05	+ 0.08	– 0.05	
P-2-N			579.47	577.91	579.32	577.69	+ 0.15	+ 0.22	+ 0.15	
P-3-N			579.35	578.34	579.7	577.74	– 0.35	+ 0.60		no access, bent 30 degrees
P-44-N			578.56	577.84	578.62	577.2	– 0.06	+ 0.64	– 0.06	
[redacted]	S 1697.55	E 1194.59	576.71	576.91	579.25	577.01	[redacted]	– 0.10		cut down to flush mount
P-6-N	S 1544.02	E 0834.53			579.14	576.48				cut down to flush mount, but not surveyed
PM-2-NC			580.29	581.02	580.29	580.99	+ 0.00	+ 0.03	+ 0.00	obstructed, measured wrt TC
PM-4-NA			579.3	576.76	579.33	576.83	– 0.03	– 0.07	– 0.03	
RE-5-NB	N 0437.18	E 0152.32	579.18	577.89						extraction well
RE-8-NB	S 0094.28	E 0130.64	577.48	575.95						extraction well
RFIMW-10			582.57	580.73	582.56	580.65	+ 0.01	+ 0.08	+ 0.01	
RFIMW-11			578.28	577.24	578.42	576.71	– 0.14	+ 0.53	– 0.14	
RFIMW-17			587.48	585.76	587.51	585.72	– 0.03	+ 0.04	– 0.03	
RFIMW-20	S 1313.56	E 1185.10	578.04	578.33	577.98	578.45	+ 0.06	– 0.12	+ 0.06	concrete slightly sunken

Piezometer	SITE COORDINATES[1] North / South	SITE COORDINATES[1] East / West	ELEV TOP WELL[1]	GROUND ELEV[1]	PREVIOUS TOP WELL[2]	PREVIOUS GROUND ELEV[2]	Δ TW[3]	Δ GRND[3]	Δ WL[4]	NOTES
	feet	feet	feet	feet	feet	feet	feet	feet	feet	
RFIMW-21			586.56	584.63	586.64	584.73	– 0.08	– 0.10	– 0.08	silty
RFIMW-27			577.69	575.71	577.67	575.63	+ 0.02	+ 0.08	+ 0.02	silty
RFIMW-29			579.82	578.44	580.26	578.21	– 0.44	+ 0.23		no access, bent at 45 degrees
RFIMW-5			582.82	580.71	582.85	580.71	– 0.03	+ 0.00	– 0.03	
RFIMW-6			582.09	580.14	581.94	580.07	+ 0.15	+ 0.07	+ 0.15	
RFIMW-7			589.98	587.67	590.03	587.77	– 0.05	– 0.10	– 0.05	
RFIMW-8			581.59	579.24	581.59	579.11	+ 0.00	+ 0.13	+ 0.00	
RFIMW-9			579.71	577.83	579.73	577.83	– 0.02	+ 0.00	– 0.02	
RP-2-NA	S 1734.40	E 0189.42	577.22	576.36	577.22	576.34	+ 0.00	+ 0.02	+ 0.00	RP_M2NA on inside lid, rotten egg odor
RP-2-NB			579.5	578.24	579.51	577.24	– 0.01	+ 1.00	– 0.01	v. silty
RP-35-N	S 2134.37	W 0289.11	577.74	578.11						
RPM-1-NC	N 1774.15	E 0364.98	581.18	580.42	581.22	580.54	– 0.04	– 0.12	– 0.04	
RPM-2-NA	S 1359.17	E 0497.12	578.2	577.11	580.54	578.74	[redacted]	– 1.63		v. silty
RPM-3-NA	S 1745.29	E 0069.42	576.73	576.31	576.75	575.74	– 0.02	+ 0.57	– 0.02	in soil pile, silty

NOTES:
[1] SURVEYED BY URBAN ENGINEERING MARCH 2002
[2] Elevations from BASF spreadsheet: "NW-GW Summary.xls", adjusted to IGLD 1985. NW-GW Summary uses elevation data from a 1996 survey of the site.
[3] change in elevation with respect to previous data (TW → top of well, GRND → ground surface)
[4] change in water level inferred by change in top of well elevation – previous data not adjusted.

Table 3. Water Level Data and Comparative Statistics

MONITORING POINT	SITE COORDINATES N / S	SITE COORDINATES E / W	UNIT	ELEV TOP WELL	GROUND ELEV [1]	WATER DEPTH [2]	WATER ELEV [1]	CALIB TARGET [3]	MONITOR AVG [4]	DIFF WRT CALIB TARGET [5]	DIFF WRT MONITOR AVG [6]	NOTES
	feet	feet		feet	feet	feet	feet	feet	feet	feet	feet	
CMS-MW-1	N 3063	W 0414	Fill	583.00	581.01	7.05	575.95	575.37	575.38	+ 0.58	+ 0.58	
CMS-MW-10	S 1445	E 1275	Fill	576.77	577.14	2.51	574.26	573.51	573.10	+ 0.75	+ 1.16	stamped P7N, marked CMS-MW-10 on concrete pad
CMS-MW-11	S 2133	E 1117	Fill	579.66	577.28	6.60	573.06	573.36	572.47	– 0.30	+ 0.59	v. silty
CMS-MW-12	S 1906	E 0790	Fill	579.55	576.91	3.35	576.20	574.32	574.82	+ 1.88	+ 1.38	
CMS-MW-13F	S 1954	E 0424	Fill	580.14	577.96	3.52	576.62	574.14	574.69	+ 2.48	+ 1.93	
CMS-MW-13S	S 1959	E 0425	Native Sand	580.44	578.05	5.18	575.26	574.13	574.16	+ 1.13	+ 1.11	
CMS-MW-14S	S 1986	E 0167	Native Sand	580.03	577.57	4.25	575.78	574.25	574.54	+ 1.53	+ 1.24	in road bed, silty
CMS-MW-15	N 3097	E 0293	Fill	577.65	577.85	3.30	574.35	573.88	573.88	+ 0.47	+ 0.48	
CMS-MW-16	N 1624	E 0931	Fill	584.79	581.99	5.82	578.97	576.18	576.82	+ 2.79	+ 2.15	
CMS-MW-18	S 0918	E 1426	F&NS (?)	577.62	577.77	2.66	574.96	573.71	573.69	+ 1.25	+ 1.27	bentonite swollen
CMS-MW-2	N 3093	W 0093	Fill	577.98	578.33	2.45	575.53	574.69	574.84	+ 0.84	+ 0.69	
CMS-MW-3	N 2883	E 0225	Fill	578.72	578.95	2.91	575.81	574.79	575.03	+ 1.02	+ 0.78	
CMS-MW-4	N 2369	E 0453	Fill	582.42	580.68	5.92	576.50	575.15	575.52	+ 1.35	+ 0.99	v.silty
CMS-MW-5	N 1164	E 1367	Fill	583.93	581.50	8.05	575.88		574.78		+ 1.10	
CMS-MW-6	N 0632	E 1519	Fill	588.21	586.68	12.60	575.61	574.71	574.73	+ 0.90	+ 0.89	
CMS-MW-7	N 0007	E 1511	Fill	580.57	578.34	4.92	575.65	573.95	573.79	+ 1.70	+ 1.86	
CMS-MW-8	S 0606	E 1486	Fill	579.92	577.40	5.29	574.63	573.55	573.33	+ 1.08	+ 1.30	
CMS-MW-9	S 1154	E 1288	Fill	577.93	578.22	4.29	573.64	573.27	572.71	+ 0.37	+ 0.93	v.v. silty
DNR-2	N 1670	W 0619	Native Sand	583.50	583.21	3.50	580.00	578.95	579.05	+ 1.05	+ 0.95	0.8' top with lock, knocked off
GTI-PW-1	N 2071	W 0063	F&NS	583.34	580.72	4.66	578.68	577.79	577.90	+ 0.89	+ 0.78	indistinct WL signal
GTI-TMW-2	N 2586	E 0058	F&NS	584.64	582.85	8.01	576.63	575.53	575.51	+ 1.10	+ 1.13	
GTI-TMW-3	N 2072	W 0112	F&NS	582.71	580.29	4.16	578.55	577.73	577.89	+ 0.82	+ 0.66	
GTI-TMW-4	N 2275	W 0276	Fill	582.58	579.00	4.20	578.38	577.57	573.95	+ 0.81	+ 4.43	
GTI-TMW-5	N 2010	W 0118	Fill	582.17	579.84	3.69	578.48	577.33	577.36	+ 1.15	+ 1.12	bent
P-11-N	S 1119	W 0087	Native Sand	576.69	574.68	2.02	574.67	573.23	573.22	+ 1.44	+ 1.45	surface flooded
P-15-N	S 0507	W 0033	F&NS	578.40	576.20	3.27	575.13	573.70	573.73	+ 1.43	+ 1.40	
P-16-N	N 0607	E 0885	Fill	587.63	585.38	3.65	583.98	580.13	580.59	+ 3.85	+ 3.39	silty
P-1-NA	S 1868	E 0694	Native Sand	581.20	579.31	7.03	574.17	573.80	573.77	+ 0.37	+ 0.40	
P-1-NC	N 1707	W 0198	Native Sand	583.05	582.08	4.57	578.48	577.77	577.77	+ 0.71	+ 0.71	

MONITORING POINT	SITE COORDINATES N / S	SITE COORDINATES E / W	UNIT	ELEV TOP WELL	GROUND ELEV [1]	WATER DEPTH [2]	WATER ELEV [1]	CALIB TARGET [3]	MONITOR AVG [4]	DIFF WRT CALIB TARGET [5]	DIFF WRT MONITOR AVG [6]	NOTES
	feet	feet		feet	feet	feet	feet	feet	feet	feet	feet	
P-24-N	N 1133	W 0024	F&NS	581.60	579.30	3.73	577.87	577.20	577.20	+ 0.67	+ 0.67	
P-28-N	N 3112	E 0319	Native Sand	578.80	576.94	5.89	572.91	573.40	573.40	– 0.49	– 0.49	stick-up bent
P-29-N	N 3112	E 0315	Fill	579.35	577.03	5.07	574.28	573.97	573.97	+ 0.31	+ 0.31	
P-2-N	S 1924	E 0733	F&NS	***579.47***	577.91	4.68	574.79	573.75	573.68	+ 1.04	+ 1.12	
P-31-N	N 2886	W 0596	F&NS	585.35	583.93	4.65	580.70	578.47	578.55	+ 2.23	+ 2.15	
P-34-N	S 1801	W 0459	F(?)&NS(?)	576.63	575.06	3.02	573.61	573.48	573.48	+ 0.13	+ 0.13	
P-35-N	S 2149	W 0287	Native Sand	578.31	578.43	3.00	575.31	574.34	575.79	+ 0.97	– 0.48	
P-36-N	N 0067	W 0463	F(?)&NS(?)	580.07	578.44	4.76	575.31	574.88	574.85	+ 0.43	+ 0.46	
P-38-N	N 2680	W 0343	Fill	584.81	582.52	6.77	578.04	577.35	577.35	+ 0.69	+ 0.69	
P-44-N	S 0594	E 0834	Fill	***578.56***	577.84	4.54	574.02	573.69	573.22	+ 0.33	+ 0.80	
P-46-N	S 1698	E 1195	Native Sand	***576.71***	576.91	4.13	572.58	573.39	573.35	– 0.81	– 0.76	
P-4-N	S 1682	E 0164	F&NS	579.06	576.57	3.76	575.30	573.81	573.81	+ 1.49	+ 1.49	in soil piles
P-5-N	S 1628	E 0464	F&NS	581.36	578.93	4.49	576.87	573.96	574.00	+ 2.91	+ 2.87	
P-6-N	S 1544	E 0834	Fill	576.61	576.48	1.35	575.26	574.02	574.02	+ 1.24	+ 1.25	
P-8-N	S 2005	E 1134	Fill	578.50	576.45	5.33	573.17	573.34	573.34	– 0.17	– 0.17	
PM-3-NB	N 0219	W 0083	Native Sand	578.57	577.89	3.54	575.03	574.53	574.52	+ 0.50	+ 0.51	
PM-3-NC	N 1780	W 0340	NS(?)	580.24	579.58	1.86	578.38	577.79	577.79	+ 0.59	+ 0.59	
PM-4-NA	S 1912	E 0791	Native Sand	***579.30***	576.76	3.64	575.66	574.29	574.62	+ 1.37	+ 1.04	
RFIMW-1	N 3096	E 0289	Native Sand	577.31	577.87	4.00	573.31	573.90	573.79	– 0.59	– 0.48	
RFIMW-10	S 1116	E 1500	Native Sand	***582.57***	580.73	10.51	572.06	572.98	572.98	– 0.92	– 0.91	
RFIMW-11	S 1483	E 1342	Native Sand	***578.28***	577.24	5.82	572.46	573.34	573.24	– 0.88	– 0.78	
RFIMW-12	S 2125	E 1157	Peat	580.53	578.20	7.71	572.82	573.24	573.21	– 0.42	– 0.39	
RFIMW-13	N 2888	E 0226	Native Sand	578.42	578.79	3.12	575.30	574.78	574.63	+ 0.52	+ 0.67	
RFIMW-14	N 2364	E 0453	Native Sand	582.40	580.51	6.43	575.97	575.15	575.10	+ 0.82	+ 0.87	silty
RFIMW-15F	N 1641	E 0868	Native Sand	585.15	583.58	8.38	576.77	576.03	576.03	+ 0.74	+ 0.75	
RFIMW-16	N 1287	E 0738	Native Sand	588.26	586.33	9.34	578.92	577.40	577.41	+ 1.52	+ 1.51	silty
RFIMW-17	N 0797	E 1003	Native Sand	***587.48***	585.76	6.82	580.66	579.12	579.16	+ 1.54	+ 1.50	
RFIMW-18	S 0081	E 1397	F&NS	579.68	577.42	5.32	574.36	574.50	574.52	– 0.14	– 0.16	
RFIMW-19	S 0525	E 1379	Fill	579.16	577.17	3.25	575.91	574.21	574.23	+ 1.70	+ 1.68	
RFIMW-2	N 2631	E 0450	Native Sand	580.69	578.59	5.34	575.35	574.73	574.72	+ 0.62	+ 0.63	
RFIMW-20	S 1314	E 1185	Fill	***578.04***	578.33	3.02	575.02	573.72	573.74	+ 1.30	+ 1.28	concrete slightly sunken

MONITORING POINT	SITE COORDINATES N / S	SITE COORDINATES E / W	UNIT	ELEV TOP WELL	GROUND ELEV [1]	WATER DEPTH [2]	WATER ELEV [1]	CALIB TARGET [3]	MONITOR AVG [4]	DIFF WRT CALIB TARGET [5]	DIFF WRT MONITOR AVG [6]	NOTES
	feet	feet		feet	feet	feet	feet	feet	feet	feet	feet	
RFIMW-21	N 0468	E 0872	Native Sand	***586.56***	584.63	10.24	576.32	575.69	575.45	+ 0.63	+ 0.87	silty
RFIMW-22	N 3094	W 0088	Native Sand	577.79	578.46	3.51	574.28	574.67	574.38	– 0.39	– 0.10	
RFIMW-23	N 3063	W 0420	Native Sand	582.81	580.94	6.83	575.98	575.39	575.35	+ 0.59	+ 0.63	
RFIMW-24	N 2824	W 0591	Native Sand	583.01	583.31	2.90	580.11	578.47	578.50	+ 1.64	+ 1.61	
RFIMW-25	N 1520	W 0566	Native Sand	581.98	582.30	2.01	579.97	579.09	579.11	+ 0.88	+ 0.86	
RFIMW-26	N 0475	W 0578	Native Sand	582.60	582.96	3.69	578.91	578.48	578.52	+ 0.43	+ 0.39	3" of ice in casing
RFIMW-27	S 0608	W 0067	Native Sand	***577.69***	575.71	3.00	574.69	573.39	573.35	+ 1.30	+ 1.34	silty
RFIMW-28	S 1711	W 0034	Native Sand	578.05	575.00	3.67	574.38	573.52	573.50	+ 0.86	+ 0.88	
RFIMW-29	S 2195	W 0013	Native Sand	***579.82***	578.44			574.12	573.74			no access, bent at 45 degrees
RFIMW-3	N 2360	E 0659	Native Sand	581.70	579.48	6.49	575.21	575.10	575.10	+ 0.11	+ 0.11	
RFIMW-4	N 1930	E 0950	Fill	581.03	578.55	5.11	575.92	574.04	573.98	+ 1.88	+ 1.94	
RFIMW-5	N 1560	E 1201	Fill	***582.82***	580.71	6.74	576.08	574.51	574.39	+ 1.57	+ 1.69	
RFIMW-6	N 1162	E 1414	Fill	***582.09***	580.14	7.66	574.43	574.43	573.90	+ 0.00	+ 0.53	
RFIMW-7	N 0610	E 1555	Fill	***589.98***	587.67	13.87	576.11		574.94		+ 1.17	
RFIMW-8	N 0025	E 1687	Native Sand	***581.59***	579.24	10.56	571.03	572.92	572.88	– 1.89	– 1.85	
RFIMW-9	S 0547	E 1591	Native Sand	***579.71***	577.83	7.89	571.82	572.72	572.68	– 0.90	– 0.85	
RFIMW-PZ1	N 2734	E 0269	Native Sand	582.70	580.85	7.27	575.43	574.94	574.94	+ 0.49	+ 0.49	
RP-2-NA	S 1734	E 0189	Native Sand	***577.22***	576.36	2.09	575.13	573.89	573.96	+ 1.24	+ 1.17	RP_M 2NA inside lid, rotten egg odor
RP-2-NB	S 0761	E 0659	Native Sand	***579.50***	578.24	4.84	574.66	573.75	574.11	+ 0.91	+ 0.55	v.sillty
RP-35-N	S 2134	W 0289	Native Sand	***577.74***	578.11	DRY						Replaces P-35-N which was left in place (damaged).
RPM-2-NA	S 1359	E 0497	Native Sand	***578.20***	577.11	3.00	575.20	574.00	576.40	+ 1.20	– 1.20	v.sillty
RPM-3-NA	S 1745	E 0069	Native Sand	***576.73***	576.31	1.89	574.84	573.75	574.00	+ 1.09	+ 0.85	in soil pile, silty
WHI-1-2S	N 2832	W 0037	Native Sand	581.56	581.68	5.22	576.34					
WHI-1-3S	N 2911	W 0260	Native Sand	579.77	580.01	3.61	576.16					
WHI-2-1S	N 2430	W 0647	Native Sand	584.49	584.72	3.93	580.56					
WHI-2-2S	N 2233	W 0440	Native Sand	581.71	581.93	2.67	579.04					silty 3.5m E of pavement
WHI-2-3S	N 2032	W 0668	Native Sand	583.20	583.50	3.18	580.02					
WHI-3-1S	N 1366	W 0709	Native Sand	583.50	583.68	3.52	579.98					
WHI-3-2S	N 0954	W 0452	Native Sand	581.28	581.49	2.03	579.25					
WHI-3-3S	N 0717	W 0753	Native Sand	584.95	585.20	5.05	579.90					

MONITORING POINT	SITE COORDINATES		UNIT	ELEV TOP WELL	GROUND ELEV[1]	WATER DEPTH[2]	WATER ELEV[1]	CALIB TARGET[3]	MONITOR AVG[4]	DIFF WRT CALIB TARGET[5]	DIFF WRT MONITOR AVG[6]	NOTES
	N / S	E / W										
	feet	feet		feet	feet	feet	feet	feet	feet	feet	feet	
WHI-4-1S	S 0396	W 0477	Native Sand	577.98	578.14	2.61	575.37					silty
WHI-4-2S	S 0894	W 0619	Native Sand	577.67	577.95	2.45	575.22					
WHI-5-1F	S 2162	E 0877	Fill	575.74	576.16	2.70	573.04					silty
WHI-5-1S	S 2161	E 0874	Native Sand	575.61	576.15	2.99	572.62					v. silty 2m E of 5.1F
WHI-5-2F	S 2043	E 0470	Fill	577.27	577.47	0.99	576.28					v. silty
WHI-5-2S	S 2047	E 0471	Native Sand	577.07	577.40	2.28	574.79					rotten eggs 1m S of 5.2F
WHI-6-1F	N 2868	E 0446	Fill	578.10	578.31	3.36	574.74					no name plate
WHI-6-1S	N 2869	E 0449	Native Sand	578.16	578.28	3.53	574.63					1m E of 6-1F
WHI-6-2S	N 2539	E 0636	NS(?)	579.88	580.12	5.00	574.88					
WHI-6-3F	N 2093	E 0491	Native Sand	580.20	580.61	3.74	576.46					
WHI-6-3S	N 2097	E 0494	Native Sand	580.20	580.77	3.95	576.25					1m N of 6-3F
WHI-6-4F	N 2205	E 0823	Fill	580.72	580.84	5.89	574.83					
WHI-6-4S	N 2207	E 0828	Fill	580.74	580.91	5.93	574.81					2m W of 6-4F
WHI-6-5F	N 1928	E 0734	Fill	579.32	579.82	2.81	576.51					
WHI-6-5S	N 1927	E 0738	Native Sand	579.60	579.75	3.13	576.47					1m E of 6-5F
WHI-7-1F	N 1251	E 1145	Fill	580.90	581.14	0.00	580.90					slip cap - flowing
WHI-7-2F	N 0761	E 1276	Fill	581.81	582.23	0.00	581.81					slip cap - flowing
WHI-7-3F	N 0302	E 1424	Fill	582.69	583.13	3.02	579.67					slip cap
WHI-7-4F	N 0479	E 1106	Fill	583.81	584.20	0.81	583.00					slip cap, water in casing
WHI-7-4P	N 0476	E 1107	Peat	583.80	584.17	0.69	583.11					slip cap
WHI-8-2F	S 0891	E 1572	Fill	577.83	578.24	5.06	572.77					slip cap
WHI-9-1F	S 0287	E 1054	Fill	576.97	577.23	2.05	574.92					
WHI-9-1S	S 0291	E 1053	Native Sand	577.11	577.33	2.39	574.72					1m S of 9-1F
WHI-9-2F	S 0632	E 1206	Fill	576.54	576.81	0.74	575.80					area flooded, screw cap, no concrete
WHI-9-2S	S 0649	E 1205	Native Sand	576.46	576.78	1.79	574.67					6m S of 9-2F - slip cap, no concrete, silty
WHI-9-3F	S 0891	E 1075	Fill	577.74	578.15	2.65	575.09					silty, slip cap
WHI-9-4F	S 1161	E 1000	Fill	578.28	578.62	2.88	575.40					
WHI-9-5F	S 1332	E 0931	Fill	577.39	577.83	2.15	575.24					

MONITORING POINT	SITE COORDINATES N / S	SITE COORDINATES E / W	UNIT	ELEV TOP WELL	GROUND ELEV [1]	WATER DEPTH [2]	WATER ELEV [1]	CALIB TARGET [3]	MONITOR AVG [4]	DIFF WRT CALIB TARGET [5]	DIFF WRT MONITOR AVG [6]	NOTES
	feet	feet		feet	feet	feet	feet	feet	feet	feet	feet	
MIN						0.00	571.03	572.72	572.47	− 1.89	− 1.85	
AVG						4.40	576.12	574.96	574.96	**+ 0.82**	+ 1.05	
MAX						13.87	583.98	580.13	580.59	+ 3.85	+ 4.43	
STD.DEV.						2.43	2.50	1.80	1.83	0.92	0.95	
N						116	116	79	81	78	80	

NOTES:
[1] IGLD 1985
[2] Measured from TOP OF WELL, i.e. top of pipe, not ground and not protective casing (stick up)
[3] CALIBRATION TARGET = arithmetic average of grid of interpolated water level from the four previous monitoring events (June 1998, October 1998, December 1999, April 2001)
[4] MONITORING AVERAGE = arithmetic average of measured water levels from any of the previous monitoring events – this differs from CALIBRATION TARGET in that it does not take into account missing water levels, i.e. the CALIBRATION TARGET includes "soft" data from missed monitoring events by interpolating a water level based on neighboring wells.
[5] DIFFERENCE between February 2002 WATER LEVEL and CALIBRATION TARGET
[6] DIFFERENCE between February 2002 WATER LEVEL and MONITORING AVERAGE

Table 4. Vertical Flow

MONITORING POINT	SITE COORDINATES		GEOLOGIC UNIT	ELEV MIDDLE SCREEN	WATER ELEV	HORIZONTAL SEPARATION[1]	HEAD DIFF[2]	VERTICAL SEPARATION[3]	VERTICAL HYDRAULIC GRADIENT[4]
	N / S	E / W							
	feet	feet		feet	feet	feet	feet	feet	feet/feet
CMS-MW-1	N 3063	W 0414	Fill	575.01	575.95	5.53	− 0.03	6.07	[redacted]
RFIMW-23	N 3063	W 0420	Native Sand	568.94	575.98				
CMS-MW-2	N 3093	W 0093	Fill	572.03	575.53	5.78	+ 1.25	8.57	14.6%
RFIMW-22	N 3094	W 0088	Native Sand	563.46	574.28				
CMS-MW-15	N 3097	E 0293	Fill	571.35	574.35	3.79	+ 1.04	13.48	7.7%
RFIMW-1	N 3096	E 0289	Native Sand	557.87	573.31				
CMS-MW-3	N 2883	E 0225	Fill	573.45	575.81	4.46	+ 0.51	14.66	3.5%
RFIMW-13	N 2888	E 0226	Native Sand	558.79	575.30				
WHI-6-1F	N 2868	E 0446	Fill	570.81	574.74	3.02	+ 0.11	9.24	1.2%
WHI-6-1S	N 2869	E 0449	Native Sand	561.57	574.63				
CMS-MW-4	N 2369	E 0453	Fill	569.18	576.50	4.99	+ 0.53	12.67	4.2%
RFIMW-14	N 2364	E 0453	Native Sand	556.51	575.97				
WHI-6-3F	N 2093	E 0491	Fill	572.79	576.46	5.03	+ 0.21	9.74	2.2%
WHI-6-3S	N 2097	E 0494	Native Sand	563.05	576.25				
WHI-6-4F	N 2205	E 0823	Fill	571.42	574.83	4.66	+ 0.02	11.14	0.2%
WHI-6-4S	N 2207	E 0828	Native Sand	560.28	574.81				
WHI-6-5F	N 1928	E 0734	Fill	572.11	576.51	3.54	+ 0.04	13.2	0.3%
WHI-6-5S	N 1927	E 0738	Native Sand	558.91	576.47				
CMS-MW-16	N 1624	E 0931	Fill	569.69	578.97	65.69	+ 2.20	12.11	18.2%
RFIMW-15F	N 1641	E 0868	Native Sand	557.58	576.77				
WHI-7-4F	N 0479	E 1106	Fill	576.40	583.00	3.34	− 0.11	9.67	[redacted]
WHI-7-4P	N 0476	E 1107	Peat	566.73	583.11				
WHI-9-1F	S 0287	E 1054	Fill	569.33	574.92	3.83	+ 0.20	16.24	1.2%
WHI-9-1S	S 0291	E 1053	Native Sand	553.09	574.72				
WHI-9-2F	S 0632	E 1206	Fill	570.69	575.80	17.71	+ 1.13	14.07	8.0%
WHI-9-2S	S 0649	E 1205	Native Sand	556.62	574.67				
CMS-MW-12	S 1906	E 0790	Fill	570.51	576.20	5.31	+ 0.54	12.18	4.4%
PM-4-NA	S 1912	E 0791	Native Sand	558.33	575.66				
WHI-5-1F	S 2162	E 0877	Fill	568.89	573.04	3.12	+ 0.42	13.57	3.1%
WHI-5-1S	S 2161	E 0874	Native Sand	555.32	572.62				
WHI-5-2F	S 2043	E 0470	Fill	573.83	576.28	3.51	+ 1.49	8.78	17.0%
WHI-5-2S	S 2047	E 0471	Native Sand	565.05	574.79				
CMS-MW-13F	S 1954	E 0424	Fill	571.46	576.62	5.03	+ 1.36	8.91	15.3%
CMS-MW-13S	S 1959	E 0425	Native Sand	562.55	575.26				

	WATER ELEV	HORIZONTAL SEPARATION	HEAD DIFF	VERTICAL SEPARATION	VERTICAL HYDRAULIC GRADIENT
MIN	572.62	3.02	− 0.11	6.07	- 1.1%
AVG	575.89	8.73	+ 0.64	11.43	5.8%
MAX	583.11	65.69	+ 2.20	16.24	18.2%
STD.DEV.	2.18	15.06	0.66	2.69	6.5%
N	34	17	17	17	17

NOTES:

1 Distance from partner well, using SITE COORDINATES

2 HEAD DIFFERENCE using WATER LEVEL, i.e. $WL_{FILL} - WL_{SAND}$ (+ve → downward flow; −ve → upward flow)

3 Difference in elevation between the measuring points, taken to be the MIDDLE OF SCREEN for each unit

4 AVERAGE VERTICAL HYDRAULIC GRADIENT = HEAD DIFFERENCE / VERTICALSEPARATION,

5 DIFFERENCE between February 2002 WATER LEVEL and CALIBRATION TARGET

6 DIFFERENCE between February 2002 WATER LEVEL and MONITORING AVERAGE